VOLUME L NUMBERS 3 AND 4

THE HAWAIIAN PLANTERS' RECORD

Above: The setup in which H 109 was germinated. Below: The first seedlings raised at the Station of which both parents were known.

THIRD AND FOURTH QUARTERS 1946

HAWAIIAN SUGAR PLANTERS' ASSOCIATION

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THE HAWAIIAN PLANTERS' RECORD

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Hawaii's Insect Quarantine Problem— A Progress Report

By C. E. Pemberton

The serious problem of preventing new insect pests from entering Hawaii in planes and ships from outside countries has become increasingly difficult in recent years. Existing small appropriations for the maintenance of a few men for this work are now entirely inadequate for the protection we require. The eradication of insects carried in aircraft coming to Hawaii has assumed not only Territorial but also National importance. A discussion is presented outlining progress made by Federal and Territorial agencies to meet this new situation.

Sometime prior to, and during the period of World War II, the maintenance of existing quarantine regulations in Hawaii against insects carried in surface ships and airplanes all but collapsed. With the outbreak of war Territorial plant inspectors were denied access to Pearl Harbor and were not permitted to enter planes under Army and Navy control. This work was handled entirely by the armed forces and by a small number of collaborating inspectors under the U. S. Public Health Service and was directed primarily against mosquitoes carried in airplanes. To this extent the operations were successful and no new species of mosquitoes became established in the Islands; but the business of a deadly war conducted on a vast scale at a terrific pace prevented the interception or destruction of other and more hardy insects carried in planes, and new insects reached Hawaii and became established at an unprecedented rate. After establishment it takes some time for an insect to make itself known in a community; but by August 1944 exotic insects began to show up and every few months thereafter entomologists discovered species previously unknown in the Territory until by October 1946, a total of 21 had been recognized on Oahu and five of them had become widespread in the Territory. Of these, 9 are pests on various plants, 7 are beneficial and 5 may be said to be neutral or of no economic importance.

With the close of the war the number of aircraft arriving in Hawaii from outside regions greatly diminished but still the number of Army, Navy and civilian planes continuing to operate far exceeded the normal traffic prior to the war and the need for an expanded inspectional force to meet such planes was too great to be met by the regular group in the employ of the Territorial Board of Agriculture and Forestry. Either this body must be more than trebled or Federal aid must be supplied if the Territory is to be given reasonable protection against further invasion of foreign insect pests.

On August 20, 1945 Territorial Plant Inspectors were again allowed to inspect surface ships arriving at Pearl Harbor; but these and other similar duties at Honolulu Harbor rendered frequent examinations of incoming airplanes impossible with the limited number of men available for the work. This situation was anticipated by the Board of Agriculture and Forestry as early as 1943 and that year Colin G. Lennox, President of the Board, began negotiations with the U. S. Bureau of Entomology and Plant Quarantine with the object of securing Federal aid for plane inspection in Hawaii. In October 1945 he went to Washington to confer with government authorities on this subject. These negotiations were followed in the late Spring of 1946 by the assignment of several Federal inspectors to this work in Hawaii and also by the creation of a California-Hawaii Plant Quarantine District under a supervisor with headquarters in San Francisco and the appointment of a supervisor for Hawaii. Shortly thereafter this force was increased to about 30 inspectors with the responsibility of inspecting and treating all incoming and outgoing airplanes operating through Oahu (exclusive of inter-island service). This included all Army, Navy and commercial planes. The Federal inspectors also assumed the duty of meeting and inspecting all surface ships entering Pearl Harbor. Territorial inspectors, 14 in all, were thus relieved of airplane inspections on Oahu and ship inspections at Pearl Harbor and were restricted to attention to ships entering Honolulu Harbor and ships and planes landing at the other Islands.

In addition to material aid from Washington, an improved spray formula, more potent than the one used for mosquito eradication in airplanes, was adopted and is now being used by the Federal inspectors in all planes coming to Hawaii and, in order to centralize the responsibility for this work, the U. S. Public Health inspectors were withdrawn from this service on June 14, 1946 to leave this obligation entirely in the hands of the U. S. Bureau of Entomology and Plant Quarantine. Still further improvement in the spray formula used in airplanes is anticipated at an early date and entomologists of the local Board of Agriculture and Forestry have already developed a modified spray of great promise.

This improvement in insect quarantine, especially with respect to airplanes, was gratifying; but during the Spring of 1946 the sudden and heavy defoliation of monkeypod trees, *Samanea saman,* in Honolulu and over most of the Territory by one of the new insects, *Polydesma umbricola* Boisduval, that first appeared in June 1945, brought home to Island residents, in a striking manner, the precarious position of the Territory in relation to hundreds of other insect pests not yet in Hawaii which might enter as stowaways in airplanes coming from both tropical and temperate regions.

In consequence on May 9, 1946, Dr. H. L. Lyon, Director, Experiment Station,

H.S.P.A., addressed the Board of Directors of the Chamber of Commerce of Honolulu on this general subject, emphasizing the damage already done by new insects appearing in Hawaii during the war, warning of the imminent danger of other and more serious insects reaching the Territory via quick-flying airplanes from pest-ridden tropical regions, and presented a method of control which would greatly reduce the risk of future invasions. As a result the Board of Directors of the Chamber of Commerce appointed an Insect Pest Control Committee consisting of 17 men representing agricultural, horticultural, dairying, public health, shipping, retailing and aviation interests to consider and take appropriate action on this problem.

This committee met on May 20 and advocated the adoption of a detailed program of insect quarantine to be enforced by the proper Government agencies. A sub-committee was appointed with Dr. Lyon as Chairman to analyze this program and draw up resolutions based thereon. On May 28 this sub-committee prepared and adopted a six-point resolution which through the full committee was submitted to the Board of Directors of the Chamber. The resolution embraced a broad plan of improvement which, if rigidly carried out, would ultimately achieve in large measure the ends sought. Early in June the Chamber of Commerce transmitted this resolution to the Army, Navy, and Agriculture departments and Public Health Service in Washington, to the local Chiefs of the Army and Navy, to the California State Chamber of Commerce and to the Chambers of Commerce of a number of western cities on the mainland. The resolution was as follows:

1. Advocates the rigid enforcement of present Army and Navy regulations, and Public Health Service regulations with regard to the application of insecticides on planes en route to Hawaii from points outside these Islands.
2. Recommend that the U. S. Bureau of Entomology and Plant Quarantine develop and initiate a program which would completely disinsectize all planes arriving in Hawaii.
3. Recommend that the U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine, with the cooperation of the Army and Navy, initiate a program to control agricultural pests of economic importance on specified outlying islands.
4. Recommend that, with the cooperation of the Army and Navy, the Bureau of Entomology and Plant Quarantine establish disinsectizing stations on certain selected islands to the West and South of Hawaii, for purposes of disinsectizing all planes taking off from these islands previous to departure for Hawaii.
5. Recommend that a further study be made by the proper agencies and that steps be taken to control stowaway insects on ships.
6. Solicit fullest support of all departments of the United States government in creating and initiating a proper defense against the introduction of dangerous parasites and insects by planes into Hawaii and the Continental United States.

Ernest W. Greene, Vice-President, H.S.P.A., with residence in Washington, D. C., has also from time to time discussed with Dr. P. N. Annand, Chief of the U. S. Bureau of Entomology and Plant Quarantine, the insecure situation of Hawaii with respect to foreign and tropical insect pests and in June 1946 E. C. Zimmerman, Systematic Entomologist, Experiment Station, H.S.P.A. visited Washington to present much first-hand information to Federal plant quarantine officials on the status of new insect pests in Hawaii and to give in detail many of the hazards Hawaii is exposed to, through greatly expanded air traffic.

In addition to these appeals to the Government, Alan D. Thistle, Director, Division of Marketing, Hawaii Board of Agriculture and Forestry, was authorized and instructed by the Board to attend the annual meeting of the Western Plant Board at Missoula, Montana on June 3, 1946 and to present a resolution somewhat similar to that submitted by the Honolulu Chamber of Commerce. This resolution was prepared at conferences called by Colin G. Lennox, President of the Board, with representatives of local agricultural institutions. The resolution was unanimously adopted at the Western Plant Board meeting and transmitted to Washington.

The Interdepartmental Pest Control Committee, composed of prominent representatives of the Departments of War, Navy, Agriculture, Interior and Federal Security Agency (U.S. Public Health Service), has reacted to such appeals by prompt acknowledgement of the importance of the whole problem and given notice of much activity on their part towards further improvement in insect quarantine procedures, especially in relation to airplanes. It has recommended that (1) the Army and Navy assist the Department of Agriculture in suppressing insect pests around air bases; (2) agencies and organizations building aircraft consider designs which will minimize the hazards of transporting insects; (3) a program of research be formulated to improve disinsectization of aircraft; (4) existing quarantine laws be analyzed with the object of further improvement; and (5) all Federal agencies controlling aircraft operate closely toward better enforcement of quarantine laws.

A survey by Federal entomologists has also been made during recent months of insect pests occurring in all of the former Japanese mandated islands in order to determine specifically all dangerous insects in those regions which must be guarded against.

To strengthen further Hawaii's appeal for protection against the incursion of new insect pests, several members of the Insect Pest Control Committee of the Honolulu Chamber of Commerce met in Honolulu on October 21, 1946 to confer with Eric Beecroft, Chief, Pacific Branch, Division of Territories and Island Possessions, U. S. Department of Interior, on the general problem of control of pests carried in aircraft. After a full discussion it was recommended that the Chamber of Commerce communicate with Chambers of Commerce on the mainland urging their support for the employment of 10 additional Federal inspectors for service in Hawaii and that mainland Chambers of Commerce encourage through their congressional representatives the necessary appropriations for the establishment of insect quarantine stations on Pacific Islands to the south and west of

Hawaii where planes en route to Honolulu and the mainland can be properly disinsectized.

At the conferences of the Insect Pest Control Committee of the Honolulu Chamber of Commerce, particular emphasis has been placed on the need for the establishment of insect quarantine stations on such outlying islands as Johnston, Wake, Midway and Canton, where qualified personnel, under Federal control, will inspect and disinsectize all planes stopping there en route to Hawaii. It was also urged that surveys and insecticidal control of insects established on these islands be continuously maintained. Since most planes from the south and west of Hawaii normally stop at these places it is believed that the enforcement of these recommendations will provide greater protection to Hawaii and the mainland against future insect invasions via airplanes than by all other procedures considered or now in operation.

Gleanings From Mainland Conferences and Some Aspects of Hawaiian Entomology

By Elwood C. Zimmerman

Scientific interest in the Pacific is increasing greatly. The war has brought sharply into focus this vast, rich area which is in great need of exploration and study. The National Research Council is taking a leading role in furthering our knowledge of the region by fostering the Pacific Science Survey. The war and air transport have brought us many new problems relating to agriculture and quarantine; some of these are discussed here, together with some comments on activities which have a bearing on our work.

In April an invitation was received from the National Research Council to come to Washington, D. C., to attend the Pacific Science Conference called by the Council for June 6, 7, and 8, 1946. A selected group of scientists whose work and contributions made them authorities on various problems of the Pacific area was invited to attend. In addition, "Liaison Members" from the State Department, Army, Navy, Coast Guard, Army Air Force, Department of Interior, Department of Agriculture, Department of Commerce, U. S. Public Health Service, and other agencies who are concerned with the Pacific area were invited. Also, representatives from the Carnegie, Guggenheim, Rockefeller, Coolidge and other foundations were invited to attend as special guests. The object of the conference was "to form an active organization of scientists in various fields which will promote and coordinate research in the Pacific area." The objectives of the proposed organization were:

"(1) To formulate and sponsor a systematic program of scientific investigation in the Pacific Islands under American administration, to be conducted with the cooperation of the government agencies charged with administrative responsibilities in the area concerned.

"(2) To encourage and assist scientific research and activities throughout the Pacific area, including the establishment of field stations at key locations and the conservation of living species important to science, and to further international cooperation along these lines."

It was believed that the conference was of great importance to all of us working in the Pacific and that attendance was highly desirable. Accordingly, with expenses defrayed by the Bernice P. Bishop Museum, I left Honolulu by "Constellation Clipper" plane on May 26 in company with Peter Buck, Kenneth Emory and Harold St. John (the other delegate from Hawaii, John Embree, went independently).

The opening session of the Pacific Science Conference was held at the National Academy of Sciences on June 6, and from then until the closing session on June 8 there was a rapid-fire series of developments. The conference created unprecedented interest, and the official attendance was much greater than had been planned

originally. It was a privilege and a pleasure to take an active part in this momentous conference.

The assembly was divided into the following divisions: Anthropological Sciences, Earth Sciences, Oceanography and Meterology, Plant Sciences, Public Health and Medicine, Zoological Sciences. Each of these divisions met in caucus and drew up specific recommendations. These in turn were incorporated in a lengthy outline of a coordinated program of scientific research for the Pacific Islands. Space cannot be afforded here to go into detail regarding the large numbers of resolutions and recommendations proposed. Suffice it to say that if the programs outlined ever are carried to maturity, hardly a stone in the Pacific will remain unturned.

In addition to the detailed specific recommendations of the various sections, a series of general recommendations were advanced which include the following: declassification and making available pertinent materials and information now held by various governmental agencies, with particular reference to those assembled during the war; conservation of natural resources; establishment of fellowships; establishment of field stations, both floating and ashore, including base stations at Honolulu and Guam and liaison stations in the Solomons, New Guinea, French Oceania, Indonesia, the Philippines and the Galapagos; an appraisal of the state of our knowledge of the various scientific fields in the Pacific, and the compilation of a guide and bibliography; establishment of documentation centers in Washington and Honolulu; preparation of check-lists of the plants and animals of the Pacific; etc.

Committees were appointed to carry on until the plan for the permanent organization of the Pacific Science Survey has been approved officially by the National Research Council. We should hear a great deal of the Pacific Science Survey as time goes on.

During a brief stop at San Francisco on the way to Washington, insect quarantine problems were discussed with representatives of the State and Federal bureaus of entomology and plant quarantine. Much concern was shown over the increased air and sea commerce between Pacific ports and California and the possibility of the introduction of new insect pests into the State. The establishment of the mango fly *(Dacus dorsalis)* in Hawaii was viewed with special alarm.

With fueling stops at Kansas City and Chicago, the "Constellation" plane reached New York City in less than 12 hours from the Pacific Coast. No insects were seen in the plane coming from Honolulu, but at the Chicago stop, a number of small flies came aboard and presumably got off in good health at New York. Insecticide sprays (aerosol form) are used in the trans-ocean flights, but no treatment is used on mainland flights. Commercial flights of less than 24 hours between Honolulu and New York are now commonplace.

At New York a visit was made to the Department of Entomology of the American Museum of Natural History. Considerable changes have been made since my visit to that institution in 1941. Under the new chairman, Dr. Monte Cazier, excellent progress is being made in expansion, modernization, and in facilitating the work of members of the staff. The future of that department looks bright. A large number of Pacific Island insects was examined, and it is obvious that the American Museum has a big task on its hands to get its Pacific insects identified and arranged properly.

Upon reaching Washington on June 1, contact was made immediately with members of the Bureau of Entomology and Plant Quarantine and the National Museum. Dr. Harold Morrison, a world authority on the scale insects and mealybugs, gave up his Sunday and another half day to go over problems concerning the Hawaiian scale insects. He was especially helpful in aiding with the editing of the scale-insect chapter of my manuscript for "Insects of Hawaii."

On June 3, 4, and 5 a continual series of conferences were held with a number of specialists. Notable among these was a detailed and highly successful one held with A. S. Hoyt and S. A. Rohwer (assistant chiefs of the Bureau of Entomology and Plant Quarantine) and E. R. Sasscer (in charge of foreign plant quarantine). Unfortunately, Dr. Annand, Chief of the Bureau, was ill and could not attend. We discussed the problems concerning the introduction of new pests by air and sea transportation, the present situation in regard to the new pests established in Hawaii during the war years, and the fruit fly problem, with special emphasis on the newly introduced mango fly. A series of photographs taken with me to illustrate the new pests and the great damage done by them was extremely useful in transmitting to my listeners a vivid picture of our Hawaiian problems. I was asked for a series of recommendations which in my opinion would help Hawaii in its continued fight against insect pests. This I was prepared to do, and I outlined some of the problems needing special attention including the immediate strengthening of the federal quarantine force in Hawaii, renewed and vigorous support of the federal fruit fly laboratory at Honolulu with expansion of its program of broad and basic investigations of methods of control. The need of special efforts in the field of biological control was stressed particularly, for in my opinion this phase of the work has not been given the attention it should have. This session was very successful, and I came away with a feeling that the Bureau of Entomology and Plant Quarantine was deeply concerned with our problems, and genuinely sympathetic and willing to cooperate with Hawaii to the fullest extent of its resources.

As time permitted, a survey was made of a great assemblage of Pacific Island insects in the National Museum. There is so much material to be studied and reported upon that the mere thought of the enormous task involved in making the data available to science tires one. The fields of Pacific entomology are vast, and the problems intricate and difficult. It is to the best interest of all agricultural industries to support and encourage research work on insects—even if the work appears to be "academic" or "pure science," for we never know when some unknown or little-known "bug" will suddenly appear as a major pest to an industry. The more we know about pests and potential pests, the better we will be able to cope with them if they become established in our Territory and threaten our agriculture. The Pacific area bristles with bad crop pests which have not yet gained a foothold in our Islands. Yet, they are all out there as an ever-present array of potential pests which must ever be guarded against. In spite of what we do, some of them will find their way into the Territory.

These notes bring to mind our problems concerning the notorious sugar cane leafhopper. The leafhopper was first collected at a light at Waialua by Dr. R. C. L. Perkins in 1900, but it proved to be a species unknown to local entomologists. As a matter of fact, it was a species new to science—even its genus was undescribed. No

one knew where it had come from, but an entomologist working at the British Museum sent word that it was similar to, but distinct from, a Javanese species. Dr. Perkins recalled having received some cane cuttings from Australia which had eggs of a leafhopper inserted in them, and he obtained some leafhoppers from a worker in Queensland for comparative purposes. These proved to be identical with the Hawaiian pest, thus giving us the locality data we needed to enable us to go out in search for parasites in a definite area, rather than waste large sums of money and much time on a "blind" search for the home of the insect. Had an adequate insect collection been available in Hawaii at that time, however, the identity of the leafhopper probably could have been established in a matter of a few hours at most, but it took Dr. Perkins several months to obtain the pertinent data. This previously unknown pest struck our plantations like wildfire. At Pahala the 1903 yield was 18,888 tons of sugar, but the leafhopper sucked the yield off to a mere 826 tons in 1906! The economic foundation of these Islands, rooted as it is in sugar, was dissolving rapidly only a couple of years after the leafhopper was first noticed feeding on cane. However, with the home of the pest definitely ascertained through the cooperation of the British and Australian entomologists, it was possible to send our men to Queensland for parasites and predators which were successfully introduced, effecting a remarkable control on the leafhopper and saving the industry from collapse.

It will pay us to keep alert and abreast of data concerning insect collections. Entomologists have been describing new kinds of insects in the official record since 1758, and now more than a million different kinds have been recorded officially. Yet, it is probable that not much more than one half of the species existing in the world today has been recorded in literature. With this staggering assemblage confronting us, we are no longer general, know-it-all entomologists. We are now specialists in restricted and more restricted fields. But no matter how specialized we become and what phase of entomology we indulge in, we must make constant recourse to insect collections as starting points. We must know what we are working with—the insect collection supplies that information. It is basic.

In biological control work it is of primary importance to ascertain the exact natural home of the pest we seek to control before we go out in search for parasites. To this end the world's authorities on the allies of a given pest, working with the extensive collections built up in their laboratories, should be consulted at length before laying plans for field work. The taxonomist is usually in a better position than any other worker to supply this critical information. However, we should not expect too much on a moment's notice. It may take time and study before a decision can be made. It may be necessary to subsidize an outstanding specialist in order to obtain a clear-cut opinion, but this should be done if industry wishes to save in the long run.

At Harvard I visited the Museum of Comparative Zoology where one of the top-ranking insect collections of the Nation is housed. Under the capable direction of Dr. Joseph Bequaert, the newly appointed chairman of the department of entomology, a program of modernization is being carried on. Unfortunately, the staff is too small and overburdened to make the best use of their magnificent collections. However, the future of the Museum of Comparative Zoology looks bright, and we hope that the present situation will soon be alleviated. There is assembled at Har-

vard one of the most extensive collections of Pacific Island insects in North America. It has been notably expanded by the wartime collections of Dr. P. J. Darlington, Jr., who added an unequalled collection of Indo-Pacific ground beetles, and by important accessions from other sources. The Harvard collection is particularly rich in material from the Solomons, New Guinea, Australia and the Philippines.

The last week of June was spent at Riverside, California, where I visited the University of California Citrus Experiment Station and attended the Thirtieth Annual Meeting of the Pacific Slope Branch of the American Association of Economic Entomologists. There were between 300 and 400 entomologists in attendance and over 50 technical papers were read. The papers were assembled in four groups as follows: (1) Symposium on Plant Quarantine, including such papers as Armitage's "History of Plant Quarantine on the Pacific Coast," Popham's "Surveys in Relation to Pest Control Work," McKennon's "Western States Quarantine Problems," and Cooley's "Air Commerce and International Plant Quarantine"; (2) Symposium on Biological Control, including Clausen's "Present Needs in Biological Control in the United States," Smith's "The Biological Control Program in Relation to California Agriculture," Steinhaus' "The Possibilities of the Microbial Control of Insects in the Western United States," and Holloway's "Progress Report on the Biological Control of the Klamath Weed"; (3) Symposium on New Insecticides and Methods of Application, including Roark's "New Insecticides," Gunther's "Chemical Studies of DDT as an Insecticide," Woodard's "Pharmacology and Toxicology of DDT," and Lange's "New Soil Fumigants"; (4) General Papers.

The display of the mechanized equipment was a revelation to an "Hawaiian." I had never seen such an array. There were truck-mounted elevators which hoisted spray crews with high-pressure equipment over 30 feet above the ground so that a double row of trees could be sprayed from above; truck-mounted machines that applied great swaths of dust and spray at the same time; hydraulic tent-lifting equipment that pulled, with ease, great fumigating tents over citrus trees and walnut trees 40 feet high; "fog" generating machines for the application of insecticides over wide areas; airplanes in action spraying and dusting in dare-devil performances; highly efficient drills for applying new soil fumigants; mechanized poison bait mixers—and divers other equipment. The war years have brought about a noticeable quickening of mechanization. The trend will continue.

How fortunate we are that we have our sugar cane pests under biological control in Hawaii! Imagine the problems and expense involved if we had to spray or dust every cane field with insecticide in order to harvest a paying crop. How would we drench every leaf in a cane field with a poison spray or dust? If we had a pest which had to be controlled by insecticides, perhaps every plantation would have to maintain its own airplanes and associated equipment to carry on a continuous program of spraying. I should not dwell further on such gloomy phases of our work.

The Citrus Experiment Station at Riverside is carrying out very interesting experiments in the mass breeding and mass liberation of parasites in the belief, that by timing the release of overwhelming numbers of laboratory-bred parasites with a critical period in the life cycle of a pest insect, crops can be saved and yields increased. These experiments will bear careful attention; they have much merit.

One of our worst pests—the melon fly *(Dacus cucurbitae)*—is being intercepted from Hawaii in quarantine at California ports at an increased rate. No loopholes should be left open for its possible introduction to the mainland. It is of equal importance that the Mediterranean fruit fly *(Ceratitis capitata)* and the mango fly *(Dacus dorsalis)* be guarded against. Any one of these flies might cause agricultural chaos if they ever became established in California. In the citrus belt, I saw golden ripe oranges hanging on the trees and large numbers of windfalls on the ground. These fruits often hang ripe on the trees for many months before they are picked. I cannot imagine a more inviting situation for the establishment of fruit flies in California. Too few people fully realize the seriousness of fruit flies as pests. One must experience their overwhelming attacks to be fully aware of the kind and extent of the damage they cause. The problem cannot be overemphasized. Of all the insect pests which have gained entrance to Hawaii in the past 35 years, the mango fly is the most serious.

A day was spent with Prof. G. F. Ferris at Stanford University discussing scale-insect problems. Prof. Ferris has made a brilliantly executed series of unsurpassed drawings of Hawaiian scale insects for my proposed publication "Insects of Hawaii." All persons working with these insects in Hawaii will be indebted to Prof. Ferris for his cooperation.

The Division of Entomology and Parasitology at the University of California, under the stewardship of Prof. E. O. Essig, is probably the largest, best equipped and best financed of its kind in the country. They are expanding into new fields and are attracting an ever-growing number of research workers and students. Over 50 candidates for the Ph. D. degree alone are expected this semester—a criterion of the progress and expansion of the science of entomology.

The California Academy of Sciences at San Francisco houses the finest insect collection west of Washington, D. C. The quarters are neat, modern and well cared for. The head of the Department of Entomology, Dr. E. S. Ross, is a keenly alert, and excellent worker; under his guidance the work in entomology should progress steadily. The collection is one of the richest in Pacific insects in America. It may include more than 300,000 specimens from the Indo-Pacific. It will come to be a more and more important source of information on Pacific insects as the material is prepared, studied and reported upon. The department is short-handed, however, and more help is needed to make such a large collection produce to the best advantage of science. We shall keep our eyes on the California Academy of Sciences.

The workers I met on the mainland were alert generally to Hawaii's insect problems. They find the Proceedings of the Hawaiian Entomological Society an extremely useful source of information, and its contents keep them well informed on the progress of our work. (Incidentally, many complimentary comments and notes of appreciation were received for the active part the H.S.P.A. plays in its generous underwriting the publication of the "Proceedings." It is a model for other industries to follow.) Some mainlanders are deeply concerned regarding the quarantine problems and the breakdown in quarantine during the war. The newly established mango fly has quickened interest in Hawaii as a filter-zone for the possible screening out of pests coming from the south and western Pacific.

The H.S.P.A., its workers and its work are widely known in entomological

circles. Comments were heard from various quarters expressing high regard for the Station's encouraging members of its scientific staff to pursue "pure science" studies along with their routine work. It was pointed out that such a policy always pays dividends—it makes the staff more alert, more learned, abreast of modern developments, better known and more capable.

A few workers expressed some doubt that the mango fly is a recent arrival. They thought that it was probably here for some years and was simply "overlooked." Such beliefs are unjustified in the light of observed facts. We have, per area, a large body of alert entomologists who are always looking for new immigrant insects. There is a spirit of rivalry among our local workers in reporting new finds. There is a certain modest distinction in reporting to the Entomological Society new information. We keep our collective eyes open and record new data as they come to hand. Most of us have gardens or get into the field frequently, and we would have noticed the mango fly long ago had it been here. Moreover, various workers have been surveying the fruit fly situation continuously, and the fly could not have escaped notice for very long. Trees whose fruits are now heavily infested were clean and free from attack last season. The mango fly has been with us for some months, but not years. We feel that it became established in the Islands after we captured the island of Saipan (July 1944)—the first place, to our knowledge, that our forces entered during the war which was infested with the fly. Thousands of troops, bringing with them masses of equipment, were returned from combat to Hawaii to recuperate. They may have brought more than the mango fly with them. This does not mean, however, that the fly was introduced from Saipan, although the evidence at hand points strongly to Saipan as the source, for it might have come in later from the Philippines, Formosa or elsewhere.

During the war it was a common sight to see vast arrays of battle-scarred equipment, such as tanks, amphibious vehicles, trucks, tractors, etc., returned from various island battlefields and lined up in great rows at various repair and storage depots in Hawaii. Some of this equipment had lain in field or jungle for long periods of time. It could not be inspected or fumigated or quarantined. There is no reason why much of that equipment did not shelter many kinds of insects and other animals and plant seeds while in the field. One can imagine a crippled tank being found an excellent place for spiders to spin their webs on, or caterpillars to make their cocoons in, or to be occupied by a host of insects and various animals in search of shelter, and as a place for lodgement for various kinds of plant seeds. Equipment might easily have been parked beneath fruit trees—such as the mango—and received showers of fallen, insect-infested fruits. There was no means to prevent this infested material from being carried back to Hawaii where the flies could emerge in quantities in due course. Infested fruits and plant material may have been brought to Hawaii in quantities in ship stores; these may have lain on deck at Pearl Harbor for some time after arrival. Suitable hosts for many insect pests line the shores of Pearl Harbor only a few feet or yards away from anchored or docked ships. Any number of returning servicemen might have carried fruits with them, either on planes or ships. Infested material might on many occasions have been discarded in Hawaii after landing. To me, the astonishing part of the whole picture is that so few insects have apparently come in in spite of these wartime conditions. I expect that we will find more species established than we have seen so far.

Also, it would not be surprising to find some new lizards, or even snakes established here. The introduction of the mango fly, together with a series of other insects, is just another phase of the casualties of war. Our quarantine practices cannot be blamed for these introductions. The blame lies with those guilty of instigating the war.

Some workers do not feel that the airplane is too important as a carrier of insect pests. However, all it takes to get a species established is the transportation of a single gravid female and her release in a favorable environmental situation upon arrival in the Islands. However, the other sources of importation are not being overlooked. Many pests have been introduced on their host plants and in fruits, but the insect need not be accompanied with its host material. It is a hazardous experience for any insect to be transported either by air or by sea and find conditions favorable for its establishment when it arrives in Hawaii. Even when we bring in beneficial insects and give them the best of care and aid them in establishing themselves we sometimes have failures of establishment. It is only a rare instance when a foreign species becomes established here—but they do become established, as our yearly records show. This establishment has speeded up notably during the war—an increase anticipated and to be expected with increased traffic. We have found a series of foreign insects in Hawaii which have gained entrance to the Islands by commerce, but, although they had escaped and were captured at large, a number of them near the docks, they have not succeeded in establishing themselves here. Throughout the history of quarantine work in Hawaii the Argentine ant was being intercepted, but it did not succeed in becoming established here until recently when it became well entrenched on an army post. Certain beetles have been taken repeatedly here, but they have not established themselves. On the other hand, we have data from our past experiences in biological control work in Hawaii which show that species have been established by our releasing in the field as few as two female specimens. When the Mediterranean fruit fly parasite *Opius humilis* Silvestri was introduced, three females and two males were released in the field in June 1913, but multiplied to such an extent that it was "very abundant" by October of the same year. *Opius tryoni* (Cameron), another Mediterranean fruit fly parasite, was introduced and only four males and two females were liberated in June 1913, and it was reported to be "common" in August 1914. Other data of similar nature are available.

The air and surface ships will continue to be sources of economic losses through their acting as carriers of insect pests. We cannot stop the influx entirely, but we can aid materially in cutting down the numbers which break through the barriers. We face a long-time, difficult, and at times uninspiring and discouraging task, but we must not shirk our duty if we are to protect our agriculture. We must ever be alert to problems of quarantine and lend our support wherever it is needed.

The Role of Bone Char and Activated Carbon in the Cane Sugar Industry

By Leon J. Rhodes

This paper is being presented to acquaint the reader with certain information concerning bone char and activated carbon as used in the production of refined sugar.

Most of the report has resulted from a study of the literature on the subject, and includes data on the history, composition, sources, methods of use, action, theory of action, regeneration and notes on the analysis of decolorizing carbons.

Historical:

The earliest report of the possible use of decolorizing carbon in the refining of sugar comes from the writings of Marco Polo (11, p. 107) who reported the use of ashes of certain woods in Un-guen in the thirteenth century; Un-guen is in southern China near Foochow and the Ming river. Lowitz (11, p. 107) discovered in 1785 that wood charcoal would decolorize solutions, and Kehls (6, p. xx) realized in 1793 that animal charcoal could be used in place of vegetable carbons for decolorizing solutions. At about this time Guillon (10, p. 174) suggested the use of wood charcoal for decolorizing sugar solutions.

The credit for the introduction of animal charcoal into the sugar industry is usually given to Derosne (10, p. 175) who started its use in 1812; in the same year Guillon (6, p. xx) used bone char in his factory in place of wood charcoal. In 1815 Peter and John Martineau (6, p. xxi) patented its use for refining and clarifying sugar. Dumont (6, p. xxiv) introduced the use of granular bone char in 1828, and suggested its advantages over powdered char. At that time (10, p. 175) bone char was added to the sugar solution, boiled in with the syrup, and the mixture filtered through linen bags. The char was not regenerated. Acid-washed bone char, blood char and partially charred animal matter were used in the foregoing manner. It has been reported that the material was rancid and that there was prejudice against its use.

The suggestion that bone char could be regenerated was made by Dumont and Schatten; in 1817 Joseph de Cavaillon (6, p. xxi) patented a revivification method.

About 1855 (10, p. 175) two commercial forms of bone char were used: (1) the regular form; and (2) the form known as purified animal black, prepared by digesting the ordinary product with dilute hydrochloric acid to remove most of the lime salts and give a product of higher carbon content.

During the past century the object of manufacturers has been to develop carbons with a greater capacity to remove impurities from sugar solutions. Great strides have been made, and carbons are now available with fifty times (8, p. 2) the activity

of bone char, insofar as color removal is concerned. These activated carbons have been increasingly used since 1930.

What Is a Decolorizing Carbon?

Decolorizing carbons exist in many different forms, and to list each with all pertinent data concerning it would be too long to present here. They fall into two general categories as follows:

(1) Bone char: This is a char made from bone, contains a large percentage of minerals, has a porous or cellular structure because of the nature of the bone structure itself, and consists mostly of calcium phosphate. The carbon is spread over a large surface area, being on the surface of the porous structure of the bones from which is was made.

(2) Active or activated carbons: These are usually of vegetable origin and are manufactured by various methods. Their efficiency depends upon their composition, particularly their porosity which determines the effective area for sorption. The names of some of these activated carbons are: Suchar, Nuchar, Darco, Norit, and Carbrox; there are many others, some similar and others different in structure.

Typical analyses of decolorizing carbons used in sugar refining (11, p. 100 and 123) are:

	Bone char %	Activated carbon (Suchar) %
Calcium phosphate	73.50	..
Calcium carbonate	8.50	..
Iron and aluminum oxide	0.40	..
Magnesia	0.20	..
Sulfates, sulfides, fluorides	Trace	..
Acid-insoluble ash	0.30	2-3.5 (total ash)
Total volatile	16.50	..
Carbon	9.00	97-99
Nitrogen	1.00	..
HCl soluble	..	1.2-2.4
pH of water extract	..	6.3-7

From the foregoing analyses it can be said that the activated carbons have a very high carbon content and a low ash content, and that bone char has a low carbon content and a high acid-soluble ash, mostly calcium phosphate.

Sources and Manufacture:

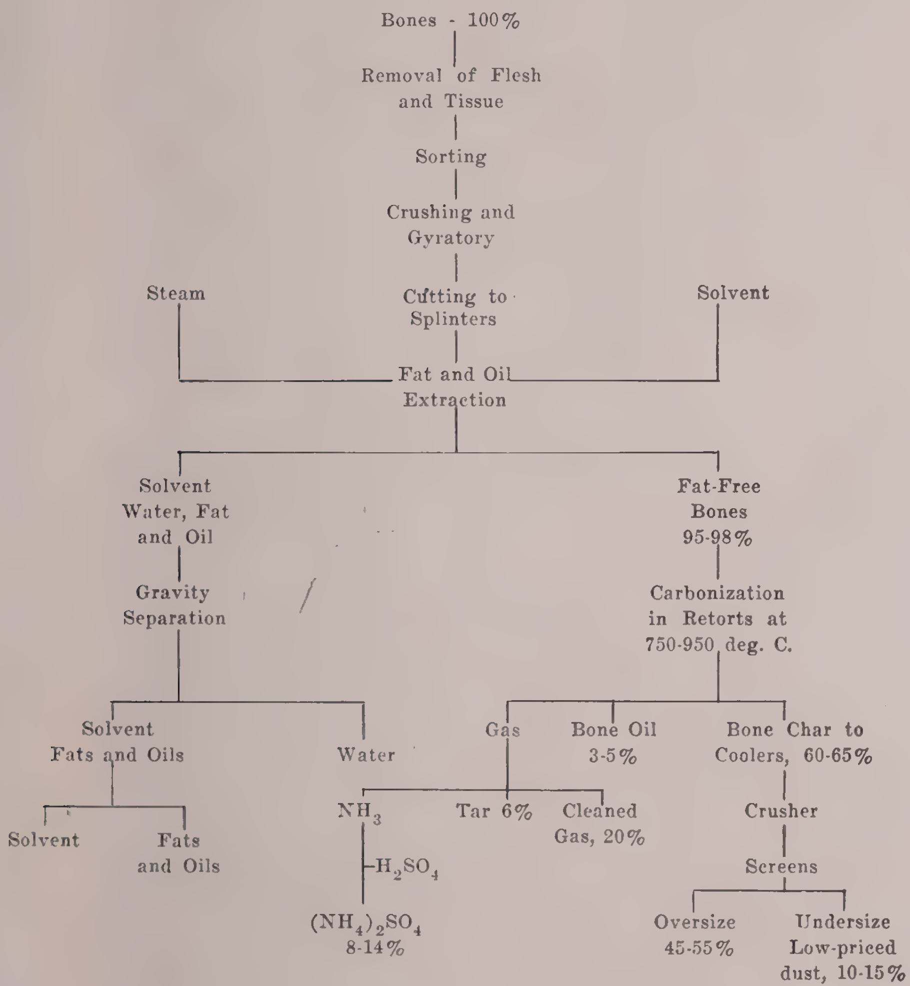
Bone Char:

Bone char is a carbonaceous residue resulting from the destructive distillation of any kind of bones. Only fresh hard bones are used because soft bones produce unsatisfactory chars. The production of bone char in the United States is about 30,000,000 pounds per year (6, p. ix).

At one time most of the bones came from the buffalo and cattle on our western plains, but later large amounts of bones came from Mexico, South America and Africa. Now, great amounts are being supplied by packing houses and butcher shops.

The following flow sheet of bone char manufacture has been taken from Mantell (11, p. 99); perhaps it will be clearer than a wordy description:

FLOW SHEET OF BONE CHAR MANUFACTURE



Harder bones yield a char which has a lower carbon content and is slightly less efficient as a decolorizing agent, but holds up a longer time in the revivifying process. Softer bones yield a pithy char higher in carbon and in capacity to remove color, but which has a shorter life.

Activated Carbons:

These carbons may be made from nearly any carbonaceous material, although most of them are of vegetable origin; hence, they are often called vegetable carbons.

Air, steam, carbon dioxide, chlorine and similar materials, involving treatment at high temperatures, are used in their manufacture (8, p. 1). Various chemicals are used for the removal of undesirable constituents. Their porosity is very important in determining efficiency.

Most of the commercial activated carbons appear as fine black powders, while some are crystalline. Their physical and chemical properties vary greatly. Depending upon their intended use, neutral, alkaline or acid activated carbons are available.

It is of interest to note some of the materials actually used for the production of activated carbons. A partial list follows (11, pp. 107-108); " . . . pine, birch, logwood, quebracho, hemlock, cedar, and other woods particularly in waste forms, such as small pieces, shavings, and sawdust, cornhusks, corncobs, corn stalks, cane trash, bagasse, peat, coals of various kinds, lignite, flue ashes, rice hulls, coffee, cocoa, mate, molasses, alcohol slop, waste liquors and extracts resulting from paper manufacture, ivory-nut shavings, coconut hulls, peach-nut shells and pits, spent olive pulp, surgical cotton, flax waste, moss, hydrogenated oil residue, rubber waste, extracted cotton hulls, and so ad infinitum." The foregoing list was taken from patent literature.

Manufacturing methods are presented in three classes, abstracted from Mantell (11, pp. 108-109):

1. The carbon is deposited as a layer on an inorganic porous base, such as kieselguhr, pumice stone or insoluble salts. The mixture is strongly heated, resulting in a deposit of the carbon on the porous medium. The structure here is somewhat similar to bone char.

2. The carbon may be deposited on a base which is subsequently removed by chemical means. The materials are usually carbonized at relatively low temperatures, and the zinc chloride, sulfuric acid, phosphoric acid, calcium chloride, etc., functioning as activating agents, afterwards removed. Another method is to treat porous woods with dehydrating agents such as lime or calcium acetate and then carbonize at white heat under lime, cool the mixture and treat with hydrochloric acid, recarbonizing a second time at red heat, excluding air. The presence of inorganic substances during carbonization prevents the formation of sorbed films of inactive material. Afterwards, acids, bases and salts are removed by chemical treatment or by leaching. Perhaps gases evolved during the decomposition of the inorganic materials during burning assist in the formation of an active carbon; nobody knows exactly.

3. Many decolorizing chars are made by carbonizing materials in retorts under controlled conditions of temperature and atmosphere. The desired porosity, strength and compactness will vary with the initial carbonization. In some instances a second carbonization is accomplished. After preparation, the carbon is activated by air, oxides of carbon, chlorine, superheated steam, or mixtures of steam and air.

What Decolorizing Carbons Do:

Just where does carbon play its role, and what does it do?

Raw sugar is the product of most cane sugar factories, since few operate a refinery. This product is usually approximately 98 per cent pure, ranging from

straw-yellow to brown in color, and contains approximately 0.5 per cent ash. The color results from the natural coloring matter in the cane or from color accumulated in the manufacturing process; the ash consists largely of potassium and sodium chlorides, calcium phosphate and sulfate, magnesium salts, iron salts, and silica. It is the function of the sugar refinery to eliminate the impurities and to produce a refined sugar of 99.9 per cent purity or higher.

Let it suffice to say that refineries are able to produce a pure white sugar through the effective use of decolorizing carbons, which remove nearly all the coloring matter and a considerable amount of the inorganic ash constituents.

How They are Used:

It is unnecessary to describe here in any great detail the processing of raw sugar to the refined product, and so only a few steps of the process will be given in order to lead to an understanding of the part played by carbon.

Bone Char:

The raw sugar goes to mixers or minglers where it is mixed with syrup, then to centrifugals where the syrup is spun off and the sugar washed. Hot water is added and the sugar is dissolved, then kieselguhr is added and the liquor filtered. This filtered liquor is ready to be decolorized, and a description, taken largely from Allen (2, p. 16-17) follows:

Bone-char decolorizing at the Crockett plant takes place in 87 char filters, each 10 feet in diameter and 20 feet high. In all of these the filter cloth, of heavy cotton twill, rests on an iron plate perforated with small holes, placed about 4 inches above the bottom of the filter. The blanket is about 2 feet larger in diameter than the filter at the point of support. The excess is available for edge packing, for which metal weights are used, held in place with wooden wedges. Fifty tons of char (minus 8 plus 24 mesh, specification, weighing about 45 pounds per cubic foot when new) are fed into each filter with the sugar liquor, the exit valve being closed. When the filter is full of liquor and char, the filling port is sealed, and a steady stream of liquor is delivered direct by pipe from the storage tanks on the floor above. The effluent pipe from each char filter is carried upward, so that the char is always submerged, irrespective of rate or amount of flow.

The rate of flow varies from 1,250 to 2,250 gallons per hour, depending on the product, the liquor remaining in contact with the char for from 1 to 4 hours. After 12 to 60 hours of service, depending on the product filtered, the char becomes impaired, indicated by a failure to decolorize satisfactorily. The filter is then drained, the syrup being returned to the filter circuit. The char is "sweetened off" with hot water to recover the greater portion of sugar, washed with hot water, then discharged through manholes near the bottom. The blanket is washed between each cycle, and removed for repair, if necessary. The problem of insuring an intimate mixture of char and syrup in the first instance was one that involved considerable research. As mentioned before, both are now added simultaneously, thorough wetting being effected by an ingenious arrangement of staggered funnels, placed in the neck of the filter. In view of the importance of close control of the color of

the various liquors, the correct handling of these to and from the char filters involves considerable personal attention.

Bone char is always revivified in refinery practice.

Activated Carbons:

The first part of the process is the same as with bone char. The filtered liquor of about 60 degrees Brix or 60 per cent sugar is mixed with the requisite amount of carbon (0.5 to 3 per cent) and the mixture filtered after a short time.

The exhausted carbon may or may not be revivified.

In each instance the decolorized syrup is boiled to grain in vacuum pans and the massecuite (mixture of crystals and mother liquor) centrifuged, the sugar dried and bagged.

How Carbon Decolorizes Sugar Solutions and Removes Impurities:

There may be a little truth in each of all the theories, some may be entirely correct, some may be wrong; so, after reading what follows take your choice or formulate a theory of your own.

It should be mentioned here that it is undoubtedly the very large surface area of special decolorizing carbons that makes them particularly effective. As an illustration of this one of the activated carbons is reputed to contain an almost unbelievable number of 120,500,000,000 particles per gram (8, p. 1), which gives an enormous surface area. It has been estimated that a cubic inch of activated carbon has an internal and external surface of more than 20,000 square yards (8, p. 2). In a rough test, the writer found approximately 100 square meters effective area per gram of "Norit," one of the activated vegetable chars. Bone char affords an enormous surface by virtue of its maze of capillaries formed by the structural calcium phosphate; no surface area values were found, but values of 46 - 268 square meters per gram appear in the literature for different wood charcoals.

In 1917 Rolph (13, p. 59) wrote: "Bone-char has the peculiar property of removing from the sugar liquor, in some unknown mechanical way, not only the soluble salts but the coloring matter as well."

In 1923 Horton (10, p. 176), of the Audubon Sugar School at the University of Louisiana, assumed that the activity of a char from any source is due to the same form of amorphous carbon produced by the low-temperature decomposition of vegetable or animal substances. The carbon is usually coated with the hydrocarbons present or a layer of ash, which in the case of bone char is soluble in water or dilute acids.

Mantell (10, p. 177) said in 1928 that another theory of the action of bone char is that the greater part of the color sorption is mechanical through the entanglement of the large molecules of colloidal coloring matter in the fine cellular structure of the char. If color is removed by mechanical entanglement, the color removal properties should be nearly as good after the carbon is burned off, which is not true. The calcium phosphate structure does remove minerals, but not color. The mechanical entanglement theory does not explain the removal of caramel, which is not colloidal, and it does not explain selective sorption.

Another theory is the condensed gases theory (10, p. 177). It was believed that carbon dioxide condensed in the pores of the char, removed lime from the sugar by

precipitating it as calcium carbonate, and that the decolorizing effect was due to oxygen condensed in the char. It is not possible to get oxygen out of char with low pressures and heat. Another idea was that hydrogen peroxide was the source of the native oxygen assumed to be the decolorizing agent, but hydrogen peroxide solutions are decomposed by bone char.

Baylis (4) wrote in 1935 that the sorption of non-electrolytes is very good evidence that sorption by active carbon is not ionic.

Alexander (1, pp. 84-85) wrote in 1937:

"Is adsorption to be considered a chemical or physical phenomenon? Because of the very great variations in the nature of adsorbents and in adsorbed substances, experimental evidence can be found to support both views, and the answer will depend upon what limitations we place on the meaning of the terms 'chemical' and 'physical'. The quantitative investigation of adsorption is not as simple as it might seem, because what are supposed to be the same adsorbents differ greatly at times in chemical and in physical structure (nature and percentage of impurities present, capillary cracks and interstices); furthermore the medium from which the adsorption is to be measured, as well as substances in it, may influence or interfere with the adsorption process, or obscure the true results. Thus 'bone black' contains calcium, phosphate, and other residual substances from the original bone. Wood charcoals generally contain alkalies."

Gortner gives some interesting views on sorption (7, pp. 214-217) partly as follows: There are two schools of thought with respect to sorption. One school considers primarily the behavior of electrolytes toward surfaces and is interested in such phenomena as acid-base exchange in minerals and soils, in acid and alkali binding of proteins, and in relationships which exist between the biocolloids and the electrolytes in biological systems and organisms. This school insists that stoichiometrical relationships account for the phenomena which we call sorption and that the union is a true salt rather than a sorptive complex. They may be partly right, for chemical combination and surface sorption involve the same chemical forces in many instances. The second school believes in purely physical surface sorption.

It has been suggested that catalytic surface activity results from a high degree of valence freedom of the surface atoms, and that less than one per cent of the surface may be catalytically active. Also, energies exist known as the van der Waal's forces which differ only in degree from primary valence forces.

Four energy sources are listed for affinities causing sorption: (a) an unpaired electron in the valence shell of an atom, (b) a positive atomic kernel (H, Na, Cu, etc.) not surrounded by electron pairs, (c) an electronegative atom or a lone electron pair in the valence shell of a negative atom, and (d) double or triple bonds in which one of the bounding electrons or electron pairs is not near the line joining the centers of the two atoms which it holds together.

The truth may lie in the intermediate ground between strictly stoichiometrical combination and purely physical surface sorption. In the rare gases surface behavior only is involved. In relatively inert organic molecules surface energies are involved, and in electrolytes we have probably in part stoichiometric unions with a residuum of surface energy attraction.

Hassler (8, pp. 61-63) has presented several interesting thoughts, an abstract of which follows:

At one time the sorptive power of active carbon was explained by the existence of a large surface area on which a film could form. It is now recognized that, although surface tension is a factor in sorption by active carbon, there are many cases where surface tension does not provide the complete answer and it is necessary to seek other causes.

The electrical potential that is found at boundaries had led to the belief that electrical forces are a factor in orientation and in sorption. It is well known that active carbons sorb both acid and basic dyes. The electrical interpretation does not explain why similar dyes are often sorbed to a different degree by the same sorbent.

The idea of a chemical reaction at surfaces may involve some adjustment in our concepts. Sorption occurs at the surface or boundary and thus depends on the extent of surface area. Sorption forces resemble the weaker bonds that unite complex compounds and hydrates, e.g., $K_4Fe(CN)_6$, $CuSO_4.5H_2O$, and are also compared with the reactions of certain dyes which combine with definite evidence of a chemical union. Sometimes the sorption bond is much stronger, e.g., certain proteins are sorbed by active carbon and can not be extracted by any known method, which is irreversible sorption.

Other sources of information contain theory along the same line of thought as the foregoing. It is hard to draw any conclusions, and the writer believes that the forces are mixed which cause sorption, and that the phenomenon can not be attributable to any one force.

Revivification of the Bone Char:

This subject will not be treated in any great detail here, for it is not intended that this paper be a technological work on the subject.

After the char has been washed thoroughly and dried, it is heated at a high temperature (preferably 1000-1100 degrees F.) without access to air. The washing may be done with dilute hydrochloric acid followed by water, or by water alone; washing with acid gives a char of increased decolorizing power. The purpose of the burning is to distill off some of the organic impurities which the washing did not remove, and to carbonize the remaining portion.

The activated vegetable carbons can be revivified by washing and re-burning, but this is usually done in only large installations; small factories using little carbon would probably not find it economical to reclaim it.

Some Notes on the Analysis of Bone Char:

This section is presented because of an interest in data determined in the laboratory, particularly on revivified bone char.

Loose and Packed Weights per Cubic Foot: The average of these two weights is determined and it has a relationship to the activity of the char. An increase in weight results from a clogging of the pore space, accumulation of inert materials, and also because the char wears smooth and packs more closely. Since the action of char is due to sorption, the less porosity the less sorption, so activity varies inversely with the weight per cubic foot. The weight should be less than 70 pounds

per cubic foot. One sample of bone char was found to have a loose weight of 66 and a packed weight of 74 pounds per cubic foot after considerable use.

Percentage of Carbon: A high percentage of carbon usually indicates an over-worked and underburned (14, p. 322) bone char. Percentages may vary probably from 4-11. Lower percentages have given satisfactory results, but 7-10 per cent is considered optimum.

Calcium Sulfate: Since quite a large percentage of the mineral content of raw sugar consists of calcium sulfate, it is only natural that the amount in the bone char will increase with the usage of the char; however, it can be kept at an acceptable figure by thorough washing. The percentage should not exceed 0.9, and should preferably be kept as low as possible.

Calcium Sulfide: This salt will vary with the sulfate content since it is formed (14, p. 322) by the reduction of the sulfates during burning, due to the presence of organic matter. It is undesirable because it gives a greenish color to the liquors, and a gray cast to the refined sugar. (Iron will also give a gray cast to the refined sugar.) The percentage of calcium sulfide should not exceed 0.4, and it should be kept as low as possible.

Calcium Carbonate: A low content indicates a low pH of the filtered liquors, which is undesirable from an inversion viewpoint of possible losses. The percentage should be about 4-9. A low percentage may be increased by feeding the char with a liquor of relatively high lime content.

pH (14, pp. 325-326): A low pH of the water extract from the bone char indicates underburning in the revivification process. This results in acid liquors and inversion losses as well as decreased mineral sorption. The pH of the char should be about 8.5-9.0. Slightly less color is sorbed at a high pH than at a lower value. A pH of over 9.6 indicates overburning.

Insoluble Ash or Silica: This percentage should approximate 0.3-0.4.

Sodium Hydroxide Test: After boiling caustic with the char, a yellow or brown color in the liquid indicates underburning and incomplete carbonization of the organic matter.

Nitrogen: Most authorities maintain that the decolorizing power of bone char varies directly with the percentage of nitrogen or nitrogenous decomposition products. Nitrogen percentages up to 7 per cent have been reported. Nitrogen compounds are necessary (6, p. 436) because regeneration of bone char is possible only as long as nitrogen is present. However, the importance of nitrogen on the decolorizing power of bone char and vegetable carbons has been refuted (14, p. 324 and 8, p. 75).

Decolorizing Power: These tests should be made on freshly burned char with liquor from raw sugar that is being refined, or from a standard sample. Comparisons should be made with good bone char or another decolorizing carbon kept as a standard. The test conditions will be somewhat arbitrary depending upon laboratory equipment, but should be kept uniform. The amount of decolorizing carbon necessary to decolorize a solution to the required degree gives a more reliable and practical test than adding equal weights of decolorizing carbon to equal amounts of the syrup to be decolorized.

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A Study in Insect Ecology Within Nests of the Mud Dauber **Sceliphron Caementarium** Drury*

By C. E. Pemberton

An investigation into the mutual relations between insects and their environment, if elaborated and analyzed in sufficient detail, will reveal much that is accountable for their behavior, abundance or scarcity and at the same time open fields for research into the unknown, always fascinating and sometimes leading to economic benefit to mankind. An account is given of the habits and complex interrelations of the various insects which may be found in the mud nests of one of the common wasps in Hawaii, emphasizing in some detail the factors responsible for the natural control of several of them.

The presence of clusters of mud cells an inch or more in length plastered in attics with unscreened louvers, on ceilings and walls of verandas, or within buildings with doors or windows constantly open, or sometimes on tree trunks or overhanging rocks and on the walls of caves, is a familiar sight to many residents of Hawaii. These mud nests have been built by the common black and yellow, thread-waisted sphecid wasp *Sceliphron caementarium* which came to the Islands from the mainland of the United States sometime prior to 1886. The nests and their contents not only serve in the first place as sealed enclosures for the development of the progeny of the original builder, but they also offer a very ready and convenient source of food or housing for a number of other insects, presenting in all a complex of insect life of absorbing interest. The investigation herein discussed has been concerned with the interrelations of the various insects found in the cells, the extent and causes of mortality amongst them and the succession in which they followed one another, as evidenced by the condition and structure of the cells and their contents when examined. It deals mostly with the wasps *Sceliphron caementarium* Drury, *Pison hospes* Sm., *Chalybion californicum* (Saussure), and *Trypoxylon philippinensis* Ashm., which store spiders in the cells; the wasp *Pachodynerus nasidens* (Latreille), which provisions the nests with caterpillars; the bee *Megachile schauinslandi* Alfken, which collects pollen and packs it into the cells; the chrysidid wasp *Chrysis extraniens* Roh. and the minute chalcidoid wasp *Melittobia hawaiiensis* Perk. which together parasitize all of the above, and lastly the dermestid beetle *Eucnocerus anthrenoides* Sharp, which was found destroying varying percentages of all but the *Melittobia*. Since the chain of events in the mud cell begins with the work of the mud dauber, we will first present a brief outline of the salient features in her life history.

In the warmer months of the year this wasp can be seen busily standing almost on her head at a muddy spot under a leaky faucet or other wet places on the

*Presidential address delivered at the Seventh Annual Meeting of the Sigma Xi Club of Hawaii, October 28, 1946.

ground, forming with her mandibles a small ball of mud with which she quickly flies to a site selected for her nest. Here the ball is pressed into position with her feet and mandibles and more is rapidly added. Back and forth she goes to her mud quarry, apparently without rest until the cell is completed some 2½ to 3 hours later. Each ball of mud is kneaded and smoothed into position both inside and out. Some observers have described her as singing at her work, for while applying the mud into position she often emits sharp, high-pitched, buzzing notes with her wings. The cylindrical cell thus formed is about an inch long and slightly over a quarter of an inch in diameter. The inner end is strongly closed with a thick wall of mud. Some years ago on a warm June afternoon, the speaker had opportunity to watch one of these builders construct a complete cell. The mud hole was 40 feet away and the home site, the ceiling of a veranda of a new house. Work began at 12:30 p.m., and regular flights were made every three or four minutes until 2:45 p.m., when the cell was completed. Other observers have noted about the same length of time required for the construction of a single cell.

When a cell is completed the wasp ceases her duties as a mud mason to become a hunter of spiders. A medium-sized spider is first located and stung in some portion of the central nervous system, quickly resulting in almost total paralysis or sometimes death of the victim. It is then carried to the finished cell and stored well inside. However, before leaving this helpless prey, the wasp places a glistening, elongate egg on it. She then continues the hunt and more spiders are captured, stung and pushed into the same cell as rapidly as she can find them. No eggs are laid on the rest of the spiders. When the cell is packed full the wasp seals the opening with a disc of mud and assumes no further responsibility over this particular unit. Though we have not had the good fortune to observe what happens if the cell is not filled with spiders by the close of day, other investigators have noted that the wasp closes the cell with a thin and temporary mud disc only to open it the following morning and complete the storing of spiders before closing it permanently. Usually a single cell will contain but one kind of spider; but in the course of her life the wasp may use more than one species.

After provisioning and closing the first cell it is usual for the wasp to add more cells against or around it until a housing unit of from a few to a dozen or more cells is made. Most of these lie in the same plane. Sometimes this wasp may, upon completing a cell, seal it up empty never to return and occasionally she abandons an empty cell without even sealing it with the usual mud cap. The cells may be laid in vertical, slanting or horizontal positions; but the latter is most frequently observed in Hawaii. As the cells are built one against another, reinforcing mud is added over and around them to make a tightly knit finished nest. We have found no evidence to indicate that this wasp ever uses a mud cell for her progeny a second time.

Returning to the egg which was placed on the first spider stored in the mud cell, there hatches from it, in from 2 to 3 days, a white, legless grub which proceeds forthwith to consume the softer parts of the prostrate spider on which it was conveniently born. The grub grows rapidly and in succession consumes all but the hard portions of the other spiders in the cell. This requires about 10 or 12 days. The mature larva then builds a thin, brown, papery cocoon around its body. The cocoon is delicately suspended to the wall of the cell by a thin network of silken

threads. Within this cocoon the larva lies for about a week, when it pupates. Some 13 days later the pupa transforms to an adult which bites its way through the cocoon, exudes a watery fluid from its mouth against the mud disk which closes the cell and bites and pushes its way out. The usual cycle from egg to adult is thus about 34 days in the summer months of the year. However, in temperate North America, where this wasp is considered indigenous, the entire winter is spent by the larva hibernating in its cocoon. This reaction to cool temperatures, evolved over a long period of time, persists in its new home in warm Hawaii and it is common knowledge here that cells containing *Sceliphron* larvae which formed late in the year, rarely produce adults until late spring the following year. The speaker collected many *Sceliphron* mud cells at Waipio, Oahu, during the fall of 1939, all of which produced adults between May 27 and June 7, 1940. Hawaii's warm climate may be limiting this habit of winter hibernation to a slight extent. A few adults were observed on the wing at Waianae, Oahu through the winter of 1939-1940 and occasionally during February in Honolulu. Dr. F. X. Williams has kindly shown me some of his field notes on this species in which he has recorded the presence in Honolulu of a few adults during the months of January, February, March and April—some appearing to be freshly emerged individuals. From all evidence this wasp produces three but rarely four generations a year in Hawaii.

Time will not permit a further discussion of many other fascinating details in the life habits of this wasp, since we are concerned here with the total picture of life in its various forms that has been manifested in the mud cell up to the time it was examined.

The life of this mud dauber is by no means a secure one. Her very existence, and that of some of the later insect visitors to the cell, is constantly threatened by serious hazards. Darwin's discourse on the struggle for existence might well have utilized the tragic events that occur within these little sealed chambers of earth.

Once our wasp has completed the construction of a mud cell, it becomes the coveted domicile for at least a dozen other species of insects in Hawaii. Some simply use the cell for housing purposes and for the rearing of their young. They enter it only when it is open and empty and seal it after one of their progeny, with special food, has been established therein. These are the wasps *Pachodynerus nasidens*, *Pison hospes*, *Megachile schauinslandi* and to a lesser extent *Trypoxylon philippinensis*, *Odynerus nigripennis*, *Nesodynerus rudolphi* and *Pison iridipennis*. One wasp, *Chalybion californicum*, opens the sealed cell, cleans out the contents stored by the original mud dauber and uses the abode for the rearing of her own progeny. Still other insects are attracted to the cells because of the living or dead arthropod material already stored or sealed therein and use such material as food for the development of their own offspring. These are *Melittobia hawaiiensis*, a true larval parasite of several of the wasps which inhabit the cells; *Chrysis extraniens*, a larval parasite of three of the wasps and a robber of their food as well; *Liposcelis divinatorius*, a scavenger; *Alaptus globosicornis* which is parasitic in the eggs of *Liposcelis*, and lastly *Eucnocerus anthrenoides*, a dermestid beetle which is predatory on most living insects occupying the cells and a scavenger on dead material also.

The habits of the mud dauber and of the other insects just mentioned have been investigated in Hawaii by several entomologists and many references can be

found in the *Proceedings of the Hawaiian Entomological Society* by Williams, Swezey, Giffard, and others bearing on one or more of these species. On the mainland Phil Rau in particular has given special attention to and contributed important papers on the habits of *Sceliphron caementarium* and *Chalybion californicum*. To appreciate our own findings with respect to the interrelations of the several species concerned, a brief summary of the uses each makes of the mud cell or its contents will be given.

Pachodynerus nasidens, a black and yellow eumenid wasp, which is native to tropical and subtropical America, came to Hawaii sometime prior to September 1911, when it was first seen about Honolulu by Giffard. He observed it storing caterpillars of the moth *Cryptoblabes aliena* Swezey in empty *Sceliphron* mud cells. Later Swezey determined that it stores caterpillars of the moths *Crocidosema lantana* Busck and *Amorbia emigratella* Busck in these cells also; while Holdaway and Look have reported observing this wasp collecting caterpillars of the bean-pod borer *Maruca testulalis* (Geyer). In the Canal Zone Rau has noted that *P. nasidens* normally builds its own mud cells in which to store caterpillars and rear its young. However, in Hawaii empty *Sceliphron* mud cells are so common that *Pachodynerus* females appear to utilize them entirely for housing purposes and have no need to construct their own cells.

Upon selecting an empty mud cell the female packs the inner half with immobilized caterpillars, attaches a single egg to the cell wall on the inside and seals all securely in by building a thin mud septum near the center of the cell. The outer half is then often similarly filled and closed with a mud cap, or sometimes closed empty, as we have frequently observed. A larva hatching from the *Pachodynerus* egg in each partitioned chamber consumes the contained caterpillars, pupates and matures to an adult which escapes by biting its way out. In the lowlands of Hawaii this is now one of the commonest of the several species of eumenidae that occur in the Islands and it is not unusual to find immature *Pachodynerus* developing in *Sceliphron* cells instead of larvae, pupae or adults of the mud dauber itself, as one inexperienced in the ways of Hawaii's larger wasps would naturally expect. After this wasp has emerged from a *Sceliphron* cell, clear evidence of its previous occupancy is left in the form of a strong, silvery, cell lining, resembling onion skin, which was made by the mature *Pachodynerus* larva prior to pupating. The particular manner in which the cell is sectioned presents further evidence of this previous occupancy. According to Williams this silvery lining to the inner wall may be found in the nests of other odineri occurring in Hawaii also.

Two other eumenids, *Nesodynerus rudolphi* and *Odynerus nigripennis*, with habits somewhat similar to *Pachodynerus*, have been occasionally observed utilizing old *Sceliphron* cells in a similar manner. According to Williams and others they also nest in porosities in stone walls and similar situations and utilize several kinds of caterpillers as food for their young.

Of the Trypoxilonidae, *Pison hospes*, a species known also in Australia, Samoa and Fiji, is a frequent visitor to old *Sceliphron* nests. Like the original mud dauber it stores spiders in the cells to serve as food for its larvae. It is also a dabbler in mud with which it partitions the cell into compartments. Mud is also used to cap the outer opening of the cell after spiders have been stored in the compartments.

A single egg is placed with each lot of spiders. After its larvae have consumed the spiders, made their cocoons and matured to adults which bite their way out, there remain the empty cocoons which have a characteristic shape by which they can be distinguished from the empty cocoons of any of the other occupants of *Sceliphron* cells. Williams noted a great mortality amongst individuals of this species when using *Sceliphron* cells for their home, apparently caused by the inability of the chambered, newly hatched adults to bite their way through the enclosing mud wall. We found considerable evidence of this also.

Pison iridipennis, a species known also in Australia and the Philippine Islands, has similar habits but is rarely found occupying *Sceliphron* cells.

One other species of Trypoxylonidae *Trypoxylon philippinensis* has been found storing spiders in old *Sceliphron* cells. Swezey records rearing this species from an old mud cell at Lahaina, Maui in 1928 and also mentions the finding of its cocoons and larvae in an old nest. The speaker has found empty *Trypoxylon* cocoons in old *Sceliphron* nests in Honolulu on several occasions.

Among the Hawaiian bees one species, *Megachile schauinslandi,* rather frequently uses empty *Sceliphron* cells for nesting purposes. This is one of the small common bees often seen gathering nectar and pollen from the flowers of cultivated plants and certain weeds. This black bee is distinguished from other megachiles in Hawaii by the rich golden band across the middle of the body. It is not native to Hawaii and is known in China and India. It frequently nests in holes in posts and other woodwork and will occasionally utilize a keyhole for this purpose. The cell is lined and closed with an exceedingly tough, sticky, resinous material by which the work of this bee is easily recognized. Before closing the cell the female fills it with a combination of pollen and nectar. With these contents is placed a single egg destined to produce a larva which consumes the rich food stored with it. The adult bee, maturing therefrom, chews its way out in spite of the tough, leathery lining of the enclosing cell. This insect will often construct a neat septum in the center of the mud cell to establish two housing units instead of one. A *Sceliphron* mud cell, once used by this bee, undoubtedly retains its gummy lining permanently or until it falls to pieces.

One of the most interesting occupants of the mud cell is a small, brilliant, metallic green wasp sometimes seen hovering about *Sceliphron* nests or on window panes or screens indoors. This is the so-called cuckoo wasp, *Chrysis extraniens.* It was first seen in Honolulu in 1914. Though the species is not known elsewhere it is definitely an immigrant to Hawaii from some other country. Its larvae are parasitic on the larvae of *Sceliphron caementarium* and to a lesser extent on those of *Pachodynerus nasidens* and *Pison hospes.* The *Chrysis* larva not only destroys the larvae of these other wasps but it also consumes food stored in the cell as sustenance for the first occupant. It is one of the mortal foes of our mud dauber. In the summer months the life cycle of this insect is about 30 days. Some mud cells examined late in May 1940 were found to contain young *Chrysis* larvae, one per cell, together with fresh spiders which the *Sceliphron* female had stored sometime previously. The *Sceliphron* larvae had already been destroyed. By late June the *Chrysis* larvae had consumed most of the spiders, pupated and transformed to adults. This species customarily hibernates through the winter in the

larval stage. *Chrysis* cocoons collected by the speaker during November 1939 did not produce adults until the following July. Some details in the life history of this wasp are unknown. How the *Chrysis* egg is placed within the sealed mud cell is still apparently unsolved. It is conjectured by some that the female slyly enters the cell and lays her egg before the *Sceliphron* female has finished provisioning it with spiders and hence before the cell has been sealed with a mud cap. It is less probable that the *Chrysis* forces her ovipositor directly through the mud wall or cap of a sealed cell in order to lay her egg therein. The quantity of spiders stored in an average cell by *Sceliphron* usually exceeds the food requirements of the *Chrysis* larva and a cell occupied by a *Chrysis* cocoon usually contains a number of unconsumed, dried-up spiders intended in the first place as food for the *Sceliphron* larva, which suffered death at the hands of the green intruder.

Another annoying associate of our *Sceliphron* is the large blue and green wasp *Chalybion californicum*. It was first seen in Hawaii by Dr. Williams on June 8, 1931. It is a common species on the mainland from whence it undoubtedly came. Phil Rau, working in Missouri, has recorded some of its remarkable habits. He found that it visited water holes or other wet spots, not for mud but for water with which it filled its gullet and carried to a *Sceliphron* cell which had been already filled with spiders and closed by the latter. The water was disgorged against the side of the cell thus enabling the *Chalybion* female to soften a spot thereon and chew a hole into the wall large enough for her head to penetrate. She then tossed out all of the spiders, cleaned out the cell, refilled it with her own collection of spiders, placed an egg on the last spider inserted and resealed the opening with mud. This sealing operation was accomplished by bringing more water to the nest or to an adjacent one and working up mud with which to close the opening. Rau called her a water carrier and a renter of houses rather than a builder. It is probable that this wasp also stores spiders in empty, open *Sceliphron* cells.

Williams and Swezey have investigated this wasp in Hawaii. It evidently also hibernates in the cell through the winter in the larval stage. Swezey collected a *Sceliphron* cell at Lualualei, Oahu on October 12, 1939, containing black widow spiders and a *Chalybion* egg. The egg hatched to a larva which consumed the spiders by October 30, spun its cocoon and remained as a larva until about March 30, 1940, when it pupated and on April 26 the adult emerged. Williams states that this wasp often plugs her stolen cell with gekko droppings which she has softened with water. The plug made by the *Chalybion* female with which to seal the cell consists of small chunks and is not smoothed out carefully as in the case of *Sceliphron* artistry. This is one bit of structural evidence left by the former by which to identify its work. Her cocoon also differs from that of *Sceliphron* since it is completely covered in a white, webby, silken network while that of the mud dauber, though remarkably similar in most respects, has no such covering.

One of the smallest insects we have observed in the mud dauber's nests is the minute tetrastichine parasite *Melittobia hawaiiensis*. This was first collected in Hawaii by Giffard in January 1907 and described by R. C. L. Perkins as a new species. Later investigations by Swezey established proof that it parasitizes the larvae of *Sceliphron caementarium, Odynerus nigripennis, Pison hospes, Pachodynerus nasidens,* and *Megachile palmarum* Perk. Williams reared it from the cocoons of *Trypoxylon bicolor* Sm. and Carl T. Schmidt has recorded the rearing

of this species from the nest of a *Polistes* wasp. In addition to the above the speaker has on several occasions found cocoons of *Chrysis extraniens* and remains of *Megachile schauinslandi* larvae filled with empty pupal exuviae of this parasite, all enclosed in *Sceliphron* mud cells. The brownish black female is about 1 mm. long and the blind yellowish male slightly larger. The females greatly outnumber the males. This insect lays many eggs upon the surface of its larval hosts. These hatch to larvae which rapidly consume the host and become adults in about three weeks after the eggs are laid. How this parasite gains entrance into the mud cell in order to parasitize the various wasp larvae above listed, has not been disclosed. Swezey reared 448 of these from a single *Sceliphron* larva. The parasite escapes from the sealed cell, after multiplying on its host, by boring out through the mud wall. Small emergence holes in such mud cells have been commonly observed by the speaker. Since they can bore out with apparent ease, it seems probable that they can also bore into new cells.

We finally come to a pillager that bores into the *Sceliphron* cell to feed on and destroy every vestige of insect life therein, whether dead or alive and who in turn seems to have no enemies whilst foraging in the cells. This is the common and prettily spotted brown, white and black dermestid beetle *Eucnocerus anthrenoides*. This omnivorous beetle was first seen in Honolulu in May 1919, when P. H. Timberlake collected a single specimen on a window. In June 1920 Dr. H. L. Lyon discovered quantities of them, together with their fuzzy, yellowish larvae in a closed can of miscellaneous garden seeds which had been stored six months previously. Many of the seeds were badly eaten by the dermestids. Later this insect acquired notoriety in Honolulu as a pest of dried and pinned insect specimens. It is known in Mexico and Panama also. J. F. Illingworth first recorded the presence of this beetle and its larvae in *Sceliphron* nests in Hawaii. These were found by him on July 8, 1929 in quantity in the cells and it was his opinion at the time that the dermestid fed on both the dead and living material occurring in these cells. In our own observations we found the beetle boring in and out of the cells and from one cell to another in the same multicellular nests. From our examinations of large numbers of mud cells we find that this insect consumes both living and dead insects and spiders in the *Sceliphron* cells. Long after this dermestid has finished its destructive work in a cell and departed, clear evidence of its former presence is left in the form of larval moults of characteristic structure and color.

The most humble of all insects that may be found in the cells is the minute Liposcelid *Liposcelis divinatorius*. This lowly, wingless scavenger enters the cell after all others have left. It will feed and multiply on organic material left in the cell by former occupants. Following it will also come excessively small hymenopterous parasites, *Alaptus globosicornis* Gir., which oviposit into the *Liposcelis* eggs and develop therein. Swezey has reared this parasite from *Liposcelis* eggs found in *Sceliphron* cells.

In addition to insects that use these cells, small spiders sometimes find the open ones convenient places for depositing their egg sacs and even Hawaiian gekkos fit their large roundish eggs therein. And lastly an enemy of the larger insects that occupy *Sceliphron* cells is the so-called tree rat *Mus rattus alexandrinus* (Geoffroy). It finds these containers a source of food in attics and other accessible places. It is not an uncommon experience for residents of Hawaii to hear on quiet nights the

falling of dried pieces of mud on attic floors overhead caused by rats breaking open *Sceliphron* nests for their contained insects.

During 1939 and 1940 the speaker had opportunity to collect and examine the structure and contents of nearly 1,000 *Sceliphron* mud cells which were taken from various situations in Honolulu, at Waipio, Oahu and at Waianae, Oahu. The cell contents and modifications, if any to the cell itself, often revealed evidence bearing on the history of the insect visitors which successively occupied it. The investigation was concerned with both the living insects found within the cells when opened and also, when possible, with facts pertaining to the activities of former inhabitants of the same cell. The following summary will indicate what had transpired, in part at least, in these cells up to the time they were examined.

In 481 of the cells examined definite evidence remained to show clearly the fate of the *Sceliphron* individuals developing therein. Of these there were 199 that had reached maturity and safely emerged to the outer world and 105 that were still in their cells in an undisturbed and normal condition either as larvae, pupae or adults about to emerge. Of the remaining 177, a total of 79 had been parasitized by *Chrysis extraniens* and 10 by *Melittobia hawaiiensis*. The dermestid *Eucnocerus anthrenoides* had destroyed 34, 3 had died in the larval stage from unknown cause and 51 had died in their cells in the adult stage apparently through inability to gnaw their way through mud walls of unusual toughness. In some instances these adults had chewed their way partially through the door of their tomb before perishing. From these data we have a mortality of at least 36.7 per cent for *Sceliphron caementarium*. We also found 52 perfectly completed cells which had been abandoned by the mother wasp without provisioning them with spiders and 24 of these were carefully closed with the usual mud cap. The causes for such apparent wasted effort were not determined.

Of the 79 cases in which the *Sceliphron* individuals had been parasitized by the cuckoo wasp *Chrysis extraniens*, the latter had in turn been parasitized by *Melittobia hawaiiensis* in 19 instances and destroyed by the dermestid *Eucnocerus anthrenoides* in 7 cases, while in 7 other cells the *Chrysis* adult matured but failed to bore out and died where it was born. Thirty-two of the *Chrysis* adults had emerged safely and 14 were found in the cells in a normal condition as larvae or pupae unharmed by parasites, predators or other adverse factors. This leaves a mortality of 41.7 per cent amongst the *Chrysis* individuals encountered.

A third occupant of *Sceliphron* mud cells which suffers heavily through enemy attack or other hazards is *Pison hospes*. This chubby, black wasp utilizes the empty cells extensively in certain localities. We found it very abundant in the Woodlawn section of Honolulu during 1940, where *Sceliphron* had built many nests under the broad eaves of a house. As previously mentioned, this insect is not harmful to our mud dauber in any of its stages and only moves into and uses open, empty cells. A total of 64 mud cells was opened which showed present or former tenancy by this wasp and revealed clear evidence of the calamitous events attending much of its progeny in this locality. In 42 cases the *Pison* larvae had been parasitized by *Melittobia hawaiiensis;* in 3 cells the larvae had been parasitized by *Chrysis extraniens* and in one instance a *Pison* pupa had been completely riddled by dermestids. Six adults had reached maturity in their cells but had died in their efforts to bore out through the tough, dry mud and in only 12 of the 64 cells examined had

the developing wasps matured safely and succeeded in emerging from their earthen enclosures. Thus, owing to natural enemies and other adverse factors, only 18.7 per cent survived to perpetuate the species. Other distractions to a peaceful existence are undoubtedly met with by this wasp even after escaping from the cell, for we found 9 cells in which the mother wasp had carefully stored spiders and sealed each cell; but had neglected to leave an egg therein in conformity with normal procedure and the spiders were beginning to dry up. Had she forgotten this final and vital operation or was she out of eggs and had no way of knowing this until the home for her progeny was prepared and provisioned? It is suggested that she at least went through the motions of egg laying, then closed the cell as a normal part of instinctive routine.

The commonest wasp in Hawaii to use empty *Sceliphron* cells for the rearing of its young is the chunky, black and yellow, American immigrant *Pachodynerus nasidens*. It is very abundant in the lowlands and most any time of the year it can be seen hovering around old mud nests or storing a caterpillar in an open cell. Like the preceding species it does no harm to the original builder, excepting perhaps when it may steal a freshly completed cell before the mud dauber has had time to store it with spiders and seal it. We observed this only on one occasion. As this wasp usually partitions the mud cell into 2 or 3 compartments and each becomes a separate housing unit, our summary which follows is based on the number of compartments examined and not on individual mud cells.

A total of 306 compartments was examined. In 82 of these the wasp larva had been parasitized by *Melittobia hawaiiensis*. In 3 compartments the larva had been parasitized by *Chrysis extraniens* and in 60 of the sections the *Pachodynerus* larva or pupa had been destroyed by the dermestid *Eucnocerus anthrenoides*. Only 4 adults were found dead in compartments from which they had been unable to extricate themselves. In 108 cases adults had matured successfully and emerged and 49 sections still contained uninjured *Pachodynerus* larvae or pupae. In these examinations the mortality amongst the progeny of this wasp was thus 48.7 per cent. Like *Pison hospes,* which we have just discussed, the *Pachodynerus* female evinces apparent flaws in her technique occasionally when preparing compartments in a mud cell for the lodging of her young. We have opened 24 cells, each partitioned once and then closed tightly by this wasp without provisioning them as usual with caterpillars. We also found one cell which had been partitioned by *Pachodynerus* and supplied with caterpillars in one section with no evidence of an egg being placed with the caterpillars; but sealed in the compartment with the shriveled caterpillars was an empty cocoon and a dead adult of the ichneumonid wasp *Cremastus flavo-orbitalis* (Cam.). The history of the events accountable for this unusual cell content is clear. One of the caterpillars which the *Pachodynerus* female had stored in the compartment had already been parasitized in the field by the *Cremastus*. As this ichneumonid is an internal parasite of various lepidopterous caterpillars, the larva in question bore no external modifications to the body and was acceptable to the *Pachodynerus* female as food for its young and was consequently carefully carried away and stored in the mud cell with other caterpillars which she had collected. As she failed to place an egg in the cell no *Pachodynerus* larva hatched to consume the caterpillars. In consequence the *Cremastus* developed to

maturity in the caterpillar stored in the sealed cell and died in a situation entirely foreign to its normal habitat.

One of the most attractive insects that occasionally uses empty *Sceliphron* mud cells, is the little black and gold bee *Megachile schauinslandi*. Only 24 cells were found which were being used or had been occupied by the progeny of this bee. Again we found evidence of considerable mortality. Thirty-three and one-third per cent of these had been destroyed by parasites or predators; there being 3 parasitized by *Melittobia hawaiiensis* and 5 consumed by the dermestid *Eucnocerus anthrenoides*. Only one adult was found which had been unable to bore out and consequently died where born. In 16 of the cells the adult had either successfully matured and escaped or there still remained healthy developmental stages of the bee.

In our studies we regret that only 6 cases were met with containing evidence of the interesting wasp *Chalybion californicum*. Of these one showed parasitism of the cocoon by *Melittobia hawaiiensis,* 3 had matured in the cell successfully and had escaped while 2 had died in the cell in the pupal stage from undetermined causes.

Of the several insects we have discussed, the little parasite *Melittobia hawaiiensis* and the dermestid beetle *Eucnocerus anthrenoides* alone appear to be free from enemies while operating in the *Sceliphron* nests. Both seem to have no difficulty in entering or leaving the cells, since we found no adult females of the former or either sex of the latter which had perished in these hard earthen chambers. It is conceivable that the dermestid could easily destroy the *Melittobia* larvae or pupae as they lie soft and helpless on their particular hosts in the cell; but we found no evidence of this.

Reference has been made to parasitism of *Pachodynerus nasidens* and *Pison hospes* by the cuckoo wasp *Chrysis extraniens*. The cases observed were rare but definite and of interest since we have no previous record in Hawaii of this *Chrysis* developing on any insects other than *Sceliphron caementarium*.

The succession of insects that live in the mud cells is subject to wide variation and to chance. However, as already inferred, some must naturally follow certain of the others. The *Chrysis* must always follow *Sceliphron, Pachodynerus* or *Pison,* since it is parasitic on these. Similarly the *Melittobia* must follow *Sceliphron, Pachodynerus, Chrysis, Pison, Megachile* or *Chalybion. Alaptus* must enter the cell after *Liposcelis* since it is parasitic in the eggs of the latter, while *Eucnocerus,* the omnivorous dermestid beetle, may follow any of the above because of its predatory and scavenger habits. Barring accidents to the cell, such as breakage by rats, the length of time a given cell may be used successively by the various insects discussed is also dependent upon the particular insects that may occupy it. If a larva of *Sceliphron, Pison, Pachodynerus, Chrysis, Chalybion* or *Megachile* becomes parasitized by *Melittobia,* or is destroyed by *Eucnocerus*, the latter two leave the cell by small holes which they bore through the wall and the cell is thus left closed excepting for these perforations and will not be open for entrance and use by the other wasps. The only insects in Hawaii that could readily use the cell thereafter would be the minute *Liposcelis divinatorius* and its egg parasite *Alaptus globosicornis*. Should *Sceliphron, Pison, Pachodynerus, Chrysis* or *Chalybion* develop to maturity in their cells and not be attacked by *Melittobia* or *Eucnocerus,*

they would emerge from their respective cells normally and leave a large opening to an empty cell sufficiently attractive for reoccupancy by some of these species again.

We found no cases of spider- or caterpillar-storing wasps using cells which had been occupied and vacated by the megachile bee. Though the cell is left open after this bee emerges, the gummy, sticky nature of the interior is apparently repugnant to these other wasps.

To illustrate in detail the varied and interesting successions of insect life that may occur in these mud cells, a single case will be cited. The cell was collected at Woodlawn, Honolulu, November 7, 1939. From the structure and contents when examined, its history could be deciphered. It had been originally built and used for progeny rearing by *Sceliphron caementarium* in the manner already described. After being vacated by this wasp, the cell was entered by a female *Pison hospes,* who sectioned it into two compartments, stored spiders in each and placed an egg in both sections, after which the cell was tightly sealed. Her larvae developed in both compartments. However a *Chrysis extraniens* female succeeded in parasitizing the larva in the front section of the cell and the *Chrysis* larva reached maturity and spun a cocoon; but female *Melittobia* entered the cell at this stage and parasitized the *Chrysis*. By this time the *Pison* larva in the other section had matured and spun a cocoon also; but the *Melittobia* females also penetrated into this inner compartment and parasitized the *Pison* larva. Then in both compartments many *Melittobia* adults matured and emerged through the cell wall from both sections and thus left the entire mud cell closed excepting for the minute emergence perforations, and empty, excepting for the tissue or chitinous remains of the several occupants which had previously undergone their various transformations therein.

Many other combinations and successions of insects were noted in the course of these studies. In tabulating the results it was found that the condition and structure of the cells examined, the insects or parts thereof present, or the various successions of insects demonstrated by the cell contents fell into 77 different categories.

Thus apart from the scanty data obtained on *Chalybion californicum* we often find clearly displayed in these small earthen nests not only the simple cases of unhampered development to maturity of *Sceliphron caementarium, Pachodynerus nasidens, Pison hospes* and *Megachile schauinslandi;* but also parasitism of *Sceliphron, Pachodynerus* and *Pison* larvae by *Chrysis extraniens* and *Melittobia hawaiiensis, Chrysis* and the megachile bee also parasitized by *Melittobia* and all but the latter frequently destroyed by the dermestid *Eucnocerus anthrenoides*. In addition we have the common mortality of several of these species at a time when they are ready to emerge as adults from the cells but die from apparent inability to break through the cells which enclose them.

As previously mentioned, the mud dauber and all but one of the several insects which occur in its nests are of foreign origin and have reached Hawaii purely by

chance. Through the retention of habits acquired in their home countries in the dim past they have gravitated together to form a natural group amongst Hawaiian insect societies. Even among these few a study of their interrelated activities presents abundant evidence of natural control of substantial magnitude in several of the units. A similar study of these in their respective places of origin, within regions supporting a rich insect fauna, would undoubtedly disclose death factors of additional diversity and complexity, contributing in all a still better state of equilibrium between the various elements comprising such a group.

Sugar-Cane Breeding In Hawaii Part I—1778-1920

By A. J. Mangelsdorf

Keen competition prevails among the various sugar-producing countries of the world. Each region is striving to find ways of producing sugar more efficiently. Some producers have already been obliged to drop out of the race because they were unable to operate as efficiently as their competitors and were losing money on their sugar crops.

One way of reducing production costs is to increase yields. And one way of increasing yields is to plant varieties which are better adapted to the particular environment and to the prevailing agricultural practices.

Although the sugar industry is a highly competitive one there has always been a lively interchange between the various sugar-growing countries of ideas and developments. Such interchange has at times been hindered, but never effectively prevented by restrictive measures enacted under momentary or prolonged economic stress.

The advantages to be realized from collaboration between competitors are clearly evident in the field of sugar-cane breeding. The very considerable progress of the past fifty years in sugar-cane improvement could only have resulted from a synthesis of the contributions of many workers in many countries.

The quest for better varieties of sugar cane which began in Hawaii with the beginning of the industry over a hundred years ago continues without abatement. The pursuit is endless; the discovery of a superior cane initiates the search for a still better one. We still have far to go. However, it may not be amiss to pause a bit and to review the path which has brought us to our present position in order to achieve a perspective which may aid us in charting our future course.

This review will take the form of a recapitulation of events. No attempt will be made to enumerate each of the many workers whose contributions have furthered the cause of sugar-cane improvement in Hawaii. Such an enumeration would have much of interest to offer, but it lies beyond our present scope. Names will be mentioned only as incidental to the events to which they are related.

The Native Hawaiian Varieties of Sugar Cane

Captain James Cook, in his account of the discovery of the Hawaiian Islands, mentions sugar cane as one of the crops grown by the natives. An entry in Captain Cook's diary (3, p. 193) for January 18, 1778, written while his two ships the Resolution and the Discovery lay anchored off the leeward coast of Kauai, contains the following observation:

> We saw no wood, but what was up in the interior part of the island, except a few trees about the villages; near which, also, we could observe several plantations of plantains and sugar canes, and spots that seemed cultivated for roots.

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Several weeks later Captain Cook recorded in his diary (3, pp. 244–245) some of his impressions of Hawaiian agriculture.

> What we saw of their agriculture, furnished sufficient proofs that they are not novices in that art. The vale ground has already been mentioned as one continued plantation of *taro*, and a few other things, which have all the appearance of being well attended to. The potato fields, and spots of sugar-cane, or plantains, on the higher grounds, are planted with the same regularity; and always in some determinate figure; generally as a square or oblong; but neither these, nor the others, are inclosed with any kind of fence, unless we reckon the ditches in the low grounds such; which, it is more probable, are intended to convey water to the *taro*. The great quantity and goodness of these articles may also, perhaps, be as much attributed to skilful culture, as to natural fertility of soil, which seems better adapted to them than to bread-fruit and cocoa-nut trees; the few which we saw of these latter not being in a thriving state, which will sufficiently account for the preference given to the culture of the other articles, though more labor be required to produce them. But notwithstanding this skill in agriculture, the general appearance of the island showed, that it was capable of much more extensive improvement, and of maintaining, at least, three times the number of the inhabitants that are at present upon it; for the far greater part of it, that now lies quite waste, seemed to be as good a soil as those parts of it that are in cultivation. We must therefore conclude, that these people, from some cause, which we are not long enough amongst them to be able to trace, do not increase in that proportion, which would make it necessary to avail themselves of the extent of their island, toward raising a greater quantity of its vegetable productions for their subsistence.

In December 1778, Captain Cook returned to the Islands after a voyage to the Bering Sea in search of a northwest passage around the American continent. His search had been unsuccessful and his food supplies were running low. His first concern upon reaching Hawaiian waters was the replenishing of his provisions.

He touched at a number of points along the leeward coast of the island of Hawaii to trade with the natives for such produce as they were able to offer. Sugar cane was among the items thus acquired.

The following remarks are found in Captain Cook's diary (3, p. 534) for Sunday, December 6, 1778.

> Having procured a quantity of sugar-cane; and having, upon a trial, made but a few days before, found that a strong decoction of it produced a very palatable beer, I ordered some more to be brewed, for our general use. But when the cask was now broached, not one of my crew would even so much as taste it. As I had no motive in preparing this beverage, but to save our spirit for a colder climate, I gave myself no trouble, either by exerting authority, or by having recourse to persuasion, to prevail upon them to drink it; knowing that there was no danger of scurvy, so long as we could get a plentiful supply of other vegetables. But, that I might not be disappointed in my views, I gave orders that no grog should be served in either ship. I myself, and the officers, continued to make use of this sugar-cane beer, whenever we could get materials for brewing it. A few hops, of which we had some on board, improved it much. It has the taste of new malt beer; and I believe no one will doubt of its being very wholesome. And yet my inconsiderate crew alleged that it was injurious to their health.

Nothing is known with certainty as to the origin of the so-called "native" varieties of sugar cane which were being grown by the Hawaiians at the time of Captain Cook's discovery of the Islands. The Polynesians may possibly have acquired their original stocks of sugar cane from the Indonesian or New Guinea

regions in the course of their eastward migrations. In any event it is probable that sugar cane accompanied the Polynesian immigration from Tahiti to Hawaii some seven hundred or more years ago.

A number of the Hawaiian varieties still survive; they have been listed and classified by W. W. G. Moir (17). They are known by such colorful names as Akilolo, Manulele, Ainakea. With their variegated stalks and leaves many of these old Hawaiian canes are colorful in appearance also.

First Recorded Attempt at Sugar-Cane Breeding

Since they were the only varieties available in Hawaii at the time, it was these native Hawaiian canes which were employed in the first attempts at commercial sugar production during the early years of the nineteenth century. However, their lack of resistance to diseases and insect pests soon became obvious to some of the pioneer planters.

The desire for better varieties found expression in a resolution passed by the Royal Hawaiian Agricultural Society at its first meeting in Honolulu on August 14, 1851. It is recorded in the *Transactions* (18, pp. 16-18) of this meeting that:

> The Society met at half past nine, the President in the chair . . . On motion of Mr. Marshall, — Resolved, That a committee be appointed to institute experiments with a view to obtain plants from the seed of the sugar cane, and to procure information on this subject.
>
> The committee appointed were, E. P. Bond, *Chairman*, D. Baldwin, G. A. Lathrop, B. Pitman.

This action indicates that the members of the Society were not conversant with the botanical "knowledge" of that period. Any well-informed botanist could have cited the belief of the leading authorities that sugar cane as a result of long-continued vegetative propagation had lost its capacity for sexual reproduction.

As we now know this belief was without foundation. However, we can appreciate the fact that the task assigned to the committee was a difficult one for several reasons. Sugar-cane seed is extremely small; a single seed weighs only a hundredth as much as a grain of wheat. The seed is short-lived; unless stored under cool dry conditions it loses its viability within a few weeks after ripening. It is exacting in its requirements for germination; the newly germinated seedlings are delicate and require intensive care.

The Committee submitted its first report at the second annual meeting of the Society (19, p. 121) in 1852.

> Sir. — The Committee appointed at the first annual meeting of the R.H.A. Society, to institute experiments with a view to obtain plants from the seed of sugar-cane, would report that, although some experiments have been attempted for the purpose proposed, yet that, owing to the lateness of the season of their appointment, and the want of facilities for conducting the experiments, they have not yet been successful.
>
> Measures have been taken to import the needful manures for conducting the experiment, and your committee hope that they may at some future time be able to present a more satisfactory report, should it be deemed advisable that they should continue their efforts.

In 1853 at the third annual meeting of the Society (20, p. 81) the Committee reported a second time;

Sir. — As chairman of the committee to obtain plants from the seed of the sugar cane, I regret to be compelled a second time to present an unsatisfactory report.

On Hawaii Mr. Pitman has been prevented from making any experiments to test the process suggested by Mr. Teschemaker, for obtaining germinating seed from the cane, he having been unable to find a suitable spot in his neighborhood in which to attempt them.

I subjoin a letter received from Mr. Pitman, from which it will be seen that he has little faith in the practical advantages which would follow success.

From Dr. Baldwin, of Maui, and Dr. Lathrop, of Oahu, the other members of the committee, I have received no report.

On Kauai, I have made some experiments, following as nearly as possible the directions of Mr. Teschemaker, but I am sorry to say that they have as yet met with no favorable result. Still the pursuit is an interesting one, and I do not yet despair of final success.

I am by no means sure that the varieties of cane which we have are the best possible for our soil and clime. The agriculture of the world may be enriched by the introduction of new varieties of the cane.

This is a subject well worthy of the continued attention of the Royal Hawaiian Agricultural Society.

Most respectfully, your obedient servant,

Edward P. Bond.

The third and last report of the Committee is recorded in the *Transactions* (21, pp. 25-26) for 1854.

The Committee to procure seed from sugar cane reported verbally, by the Chairman, E. P. Bond, who stated that no progress whatever had been made in arriving at the result desired; and read a letter from B. Pitman, Esq., a member of the Committee, which is appended:

Hilo, 10th May, 1854

To the Chairman of the Committee for producing seed from Sugar Cane.

Sir. — I had, last year, the honor to submit to you my opinion on the subject of causing the sugar cane to bear seed, in Hilo, and am this year more convinced of the impossibility of making it produce seed by artificial means. Having attentively examined the different sugar plantations in this district, I find the soil, at the depth of a few inches, to be a hard, stiff clay, produced probably by volcanic action on the substratum of tufaceous lava, or, by decomposition, re-agglutinated into a firm clay. Such is the nature of the soil generally throughout this district, on the table portions of lands situate between the ravines, varying in depth according to its proximity to larger or smaller ravines. It would therefore be impossible, from the nature and composition of the soil, to create such a chemical affinity as Mr. Teschemaker proposes; and unless such combination be effected, I can well conceive that there cannot be either seed or pollen. These remarks, however, apply particularly to Hilo. There are portions of south Kona and Puna where it might succeed; yet even then it would remain to be tested whether such seed would grow in so humid an atmosphere as Hilo possesses; or whether, by re-planting the tops of such plants here, they would not deteriorate. It would undoubtedly prove a most beneficial acquisition to the Hawaiian group, could the seed be produced; but it must be in a drier climate than that of Hilo.

Most respectfully, your obedient servant,

B. Pitman.

The failure of this pioneer effort at sugar-cane breeding is understandable. The planters of those early days were confronted by many problems. It was hardly to be expected that they should have been able to find time for the experimentation required for success in such an undertaking. Had the venture succeeded, sugar-cane breeding in Hawaii and in the world would have been advanced by many years.

Early Importation From Foreign Countries

Thwarted at the outset in their attempts to breed sugar-cane varieties of their own, some of the planters began to turn their attention to the importation of canes from other tropical countries. The presidential address of Wm. L. Lee at the third annual meeting of the Royal Hawaiian Agricultural Society (20, p. 4) in 1853 touches on this matter.

> The endeavor to cause cane to bear seed, as recommended in the valuable letter of Mr. Teschemaker, has thus far been a failure, and no effort has been made by the Society to introduce new varieties of the sugar cane from Tahiti and other countries, as it is generally thought by our oldest planters that the several kinds of native cane now in cultivation are the best adapted to our soil and climate. The Tahitian cane introduced by Messrs. Ladd & Co. about ten years since, has nearly if not entirely disappeared, and there are contradictory opinions as to its value. I think, however, that it should have a fair trial, and that the Society could not make a better expenditure of a few dollars than by reintroducing it.

The "Tahitian cane introduced by Messrs. Ladd & Co. about ten years since" is so far as we know the first importation of record. The above statement indicates, however, that the variety in question failed to establish itself as a plantation cane.

Importation of the "Lahaina" Variety

The second recorded importation is that of the cane known in other sugar-growing countries as Bourbon or Otaheite. It was brought to Hawaii in 1854 by Captain Pardon Edwards' whaleship "George Washington." The accounts as to its source are conflicting; according to one version (1, pp. 42-43) it came from Tahiti, according to others (24, pp. 116-117; 4, pp. 587-590; 23, p. 199) from the Marquesas. This cane was first planted at Lahaina where it soon demonstrated its superiority over the Hawaiian varieties.

The advent of the "Lahaina" cane with its greatly improved yields gave new life to the struggling young sugar industry. In 1876 the industry was further stimulated by the signing of the Reciprocity Treaty with the United States. This treaty assured the planters of a market for their sugar. In the rapid expansion which ensued the Lahaina variety was the one which was most extensively planted. It served the industry from its feeble beginnings when the crop amounted to only a few thousand tons a year until the early part of the present century by which time the annual crop had risen to five hundred thousand tons. For nearly half a century Lahaina retained its position as the leading variety in Hawaii.

Some of the facts pertaining to the introduction of Lahaina were recorded by D. D. Baldwin (1, pp. 42-43) in 1882.

> *To the Editor of the Hawaiian Gazette:—*
>
> Sir: The justly acknowledged superiority of the "Lahaina Cane" warrants a correct statement of the facts regarding its origin. In 1854 Capt. Edwards of the whaleship *George Washington* brought from Tahiti the two varieties of cane now commonly known as the "Cuban" and the "Lahaina." This seed was intended for Mr. Titcomb, a Kauai planter; but the ship first calling at Lahaina, Mr. Chase, U. S. Consul resident, obtained possession of it, and planted it in his Lahaina garden. Two or three years later Mr. Oudinot obtained from these cuttings of the "Cuban," and this was the variety which disturbed the slumbers of his boarders by its rapid growth. It was then often called the "Oudinot Cane," from the supposition, which the "Marshal" favored,

that it had been imported by him from Louisiana. This, and not the "Lahaina Cane," is also the variety now known as the *kenikeni*. But there is no ground for the supposition that it is so called as having been sold by Mr. Oudinot at 10 cents a stick, as dimes and the term *kenikeni* for them was quite unknown to Lahaina. The original term by which the cane was known was *kinikini*—numerous, very many, so called from its prolific nature. Latter years the terms seem to have been corrupted to *kenikeni*.

Neither do I think there is any ground for the supposition that either of these canes originally came from New Caledonia; for the Tahiti native canes have long been quoted by English writers on sugar as the best known varieties. The "Lahaina" variety can readily be distinguished by its long straight leaves of light color, heavily aculeated, or covered with prickles at the base, and its small round prominent buds; while the "Cuban" has leaves of darker green, bending down in graceful curves, with no prickles, and large triangular buds located in little cavities on the sides of the cane stalk.

During the years 1861-2, when sugar making commenced in Lahaina the *kenikeni* or "Cuban" was the favorite cane, and was universally planted there. But since then it has been almost wholly neglected, and the "Lahaina cane" has taken the preference, its great advantages being—1. Rapid growth, thus quickly covering the ground and requiring less labor for cultivating and irrigating. 2. Deep rooting, it drawing nourishment from the subsoil, or from soil the surface of which has already been exhausted by other varieties of cane. 3. Its having, when mature, a hard rind which prevents the ravages of rats. 4. The superior richness of its juice, it generally weighing one-third more than the juice of other varieties of cane cultivated under like circumstances. 5. It possesses a compact, firm fibre, which renders the trash easy to handle and enhances its value as fuel. With these advantages may be mentioned the peculiar whiteness of the juice of mature Lahaina cane, which, as far as I have been able to compare, exceeds that of any other island variety of cane, and with its superior density would naturally insure white grades of sugar.

In Lahaina as early as 1865 the juice of this cane was boiled in vacuo by the writer with fine results, it often yielding 29 ounces of sugar to one imperial gallon, or about 906 lbs. to a clarifier of 500 gallons; while other varieties of cane under like circumstances only yielded 18 or 20 ounces of sugar to the gallon, or 625 lbs. to a clarifier of the same size.

At this time several attempts were made by myself and others to introduce the Lahaina cane into Wailuku, Haiku and other localities; but the only response from planters to these incipient attempts was, that, though a good cane it doubtless owed much of its virtue to the mild warm climate and rich soil of Lahaina. It was introduced on the Kohala Plantation during the years 1871-2, and the extraordinary results there have justly brought it before the public. Further experiments are now proving its adaptation to nearly every cane-growing soil and climate on these Islands.

Importations from Mauritius and Queensland

The Lahaina variety proved to be admirably suited to the better irrigated lands particularly at the lower elevations, but it did not thrive at the higher elevations nor in regions of heavy rainfall. The desire for suitable varieties for the poorer lands led to further importations from other countries.

The danger of introducing foreign diseases and insect pests along with the planting material from abroad was not yet fully appreciated. Quarantine measures were far from adequate.

Information concerning these early introductions is at best fragmentary. No formal records were kept as to sources and dates of arrival. In compiling this

report we have drawn upon a list of references to early importations kindly supplied by Mabel Fraser, Librarian at this Station.

As chairman of the "Committee on Varieties of Cane" Theo. H. Davies (4, pp. 588-589) in 1884 wrote as follows:

I therefore believe that every planter should prepare himself for an emergency, by having a few acres of some other well selected variety planted every year to serve for seed in the event of failure of the Lahaina cane, from the sudden development of some new borer or blight. It was this conviction that led me to procure from Mr. Home at Mauritius, the seventeen varieties of cane which have been so well cared for by Mr. Jaeger, and from which distribution has been made to many plantations. I received two Wardian cases from Mr. Home containing 25 or 26 different canes, but only 17 lived, named as follows: one samnei, three brehhet, five horne, six black cane, seven canne morte, eight vulu vulu, ten miligete, eleven vituatuata, twelve nammi, fourteen vico, fifteen vagabonde, seventeen samoa, eighteen seete, nineteen lomaloma, twenty-two kamba kamba vati, twenty-three green and red striped cane, twenty-four large green cane. Amongst the canes which did not survive were twenty-five beleguet, a rose colored cane which, I understood from Mr. Home, was equal to our Lahaina cane, and the mainstay of the Mauritius planter. This beleguet is the cane I was most anxious to get, and I was much disappointed at its failure. I agree with Mr. Jaeger that further efforts should be made to procure this cane, and I hope this company will authorize the small outlay.

The first cuttings of these Mauritius canes were distributed during the first half of the present year, and it is too soon to speak of their relative value. Some of them are doing remarkably well at Laupahoehoe, at Honokaa, at Mr. Notley's, and at several other places. At Hilea, Mr. Spencer states that the white varieties planted in January at an elevation of 325 feet now strip six feet, and that there is no cane on the plantation that now promises as well as the striped varieties planted 1750 feet high, and which stood as well as Lahaina cane. In rainy districts the Mauritius canes appear to grow too thick and may do better in drier places.

The original plants can be seen now at the Agricultural Gardens in King street, opposite the residence of Captain Luce.

Queensland has supplied us with some new varieties of cane imported first to Mr. Turton which have been tried on several plantations. Amongst them are one yellow Caledonia, two big ribbon, three rose bamboo, four Ottmatie and five elephant. The result of these canes at Ookala has not been satisfactory, as stated by Mr. Soper, after three years' trial. They were introduced at Hilea in July last and appear to be growing finely. Of the result there it is too soon to speak.

At Laupahoehoe they have not done well and seem to develop a new kind of borer which has discouraged their cultivation. Mr. Rickard states that at Honokaa, at an elevation of 500 feet the vulu vulu, miligete, nammi, and loma loma seem to do very well and look healthy and vigorous, but the kamba kamba and some other varieties are very poor.

Of the indigenous and acclimatized canes there are at Hilea nineteen varieties, including the Lahaina, which was brought here first from the Marquesas and planted in Mr. Oudinot's garden at Lahaina. In the year 1865, I remember Mr. Hackfeld informing me that 1½ tons was an average and two tons a good yield per acre for sugar cane, and the comparison of the old with the new canes at Lahaina may have had something to do with the incredulity with which some of Mr. Oudinot's anecdotes were occasionally received. Mr. Spencer states that at Hilea, during the present year, he has taken 6½ tons per acre from second ratoons of Lahaina cane. He also says that under favorable conditions the 'China' yields as well as the Lahaina.

Early History of Yellow Caledonia in Hawaii

Mr. Davies' statement that Yellow Caledonia was imported first by Mr. Turton is of particular interest in view of the conflicting accounts of the introduction of the cane which was destined to succeed Lahaina as the leading variety in Hawaii.

Henry Turton was one of the organizers of Pioneer Mill Company; in the early 1880's he held a controlling interest in that plantation. From Mr. Davies' report it appears that in 1884 Yellow Caledonia had been under trial at Ookala for three years. From this it may be inferred that Mr. Turton's importation arrived during or prior to 1881. Of interest also in view of what follows is the mention in Mr. Davies' report of the introduction at Hilea in July 1884 of Yellow Caledonia, Rose Bamboo and the other canes of Mr. Turton's Queensland importation.

An account by Walter M. Giffard (13) of his recollections concerning the importation of Yellow Caledonia and Rose Bamboo appeared in *The Hawaiian Planters' Record* of January 1928. An excerpt from his account is reproduced below:

> In 1876, the writer held a clerical position with the late firm of W. G. Irwin and Company, then a copartnership, consisting of John S. Walker, Z. S. Spalding and William G. Irwin.
>
> At this period the lowland canes were mostly, if not altogether, the Lahaina, and the upland fields were planted with the so-called native varieties. In Kau, I believe that the latter predominated on the lower as well as the upper lands.
>
> General interest in new varieties was not altogether lacking, but it was not until 1879 or 1880 that concerted effort was made to introduce foreign varieties for experimental purposes.
>
> Because the origin of our cane varieties is of deep interest to all concerned in the Hawaiian sugar industry, it is important to record for future reference the recollections of those who were connected with the industry in its earlier years.
>
> The following contribution deals with the introduction of the two varieties of sugar cane known as Yellow Caledonia and Rose Bamboo, about 1880, and the subsequent distribution of the first named variety to replace the then standard Lahaina. Lahaina, even at that time, nearly fifty years ago, was suspected to be gradually deteriorating in certain localities because of attacks of what was then known as Lahaina disease, now called root-rot.
>
> W. G. Irwin and Company were agents, at that time, for two independent sugar plantations in Kau, Hilea plantation and the Hutchinson plantation, both of which cropped only the so-called Hawaiian varieties. Charles N. Spencer, the manager of Hilea, an enthusiastic collector of native canes, developed a sudden yearning to add to his collection some foreign varieties, for experiment and comparison. To this end Spencer secured the personal cooperation of John S. Walker, then the senior partner of the firm of W. G. Irwin and Company, and prevailed upon Walker to procure for the Hilea collection a selection of some of the best commercial varieties of cane grown in Queensland, Australia, in the hope that among these introductions there might be something that would eventually lead to a heavier production of sugar in Kau.
>
> In due course, a selection of sticks of Queensland cane, comprising about twelve varieties, if I remember rightly, came consigned to W. G. Irwin and Company.
>
> I have a distinct recollection of the receipt of this consignment and, in my clerical capacity, forwarding the package to Manager C. N. Spencer on one of T. R. Foster and Company's schooners at that time (1880-1881) freighting between Honolulu and the Kau ports.

Later, reports in Kau were to the effect that amongst the Queensland canes introduced, were two very promising varieties known at Hilea and Hutchinson plantations as Yellow Caledonia and Rose Bamboo. Word came to the Honolulu office that both these varieties were making an exceptional appearance alongside the native canes on Spencer's experimental plots.

Hilea plantation, in the meantime, had been incorporated as the Hilea Sugar Company, its stock owned entirely by W. G. Irwin and Company. After the death of Alexander Hutchinson, our firm bought his plantation and incorporated it. The Hutchinson mill was then at Naalehu. After Irwin and Company acquired the two places, they erected a newer and larger mill at Honuapo to grind the cane from both Hilea and Hutchinson, merging all of the sugar properties in the Hutchinson Sugar Plantation Company and discontinuing operation of the Hilea and Naalehu mills. While this was in progress, Honuapo had become the chief shipping port at the south end of the island.

The late John A. Scott, of Wainaku, Hilo, was the engineer in charge of the erection of the Honuapo mill. He continued as engineer until the owners transferred him to Hilo as manager of Wainaku plantation, which later became the Hilo Sugar Company, Limited.

While he was employed at Honuapo, Scott knew of Spencer's hobby of collecting and growing cane varieties. Later, when visiting there, he took note of the outstanding qualities of some of the new canes, especially the Yellow Caledonia. In many of his letters to W. G. Irwin and Company, written from Hilo, Scott, in discussing the need of better varieties, illustrated his theories by referring to the steady weakening of Lahaina cane at Waiakea's fields, near by.

He became much concerned over the possibility of the Lahaina disease spreading to the Wainaku fields from Waiakea and asked our office at Honolulu to get a few bags of Yellow Caledonia for him from Hilea, his idea being that if Lahaina should show signs of failure he would have another variety with which to replace it.

In consequence, a shipment of Yellow Caledonia seed cane was forwarded and in due course Scott planted quite an area with it. He in turn distributed cuttings to other plantations in the Hilo district. Later, seed of both Rose Bamboo and Yellow Caledonia were sent direct from Hilea to a number of other plantations, including Waimanalo, on Oahu. Waimanalo, I think, was the first plantation on this island to get Rose Bamboo. I distinctly recollect the first shipment to us, after W. G. Irwin and Company became agents for the plantation.

This together with the following statements fixes the time of the introduction of these two canes from Queensland, Australia, as in the year 1880, by W. G. Irwin and Company, for C. N. Spencer at Hilea; and the first shipment of Yellow Caledonia to Wainaku about 1890; the first commercializing of this variety by Hilo Sugar Company.

A letter dated September 13, 1885 from Mr. Spencer of Hilea, Kau, Hawaii to H. M. Whitney, Chairman of the Committee on Varieties of Cane, appears in the report of that Committee (23, p. 199) for 1885.

I send you herewith a list of the different varieties of cane grown on this plantation. Those from Queensland deserve special mention. The Big Elephant and Otaheate, I believe, will prove as great a blessing on our high lands as the Lahaina has on our lowlands. They average respectively 38 4-10 sticks to the hill. Both varieties have long joints and large sticks. It is the finest cane I have ever seen. I got the seed from Mr. W. G. Irwin in July, 1884, and it was planted on the 20th. The seed being dry, it was a long time before it sprouted. I cut it (for seed) on the 8th instant, and the average length of the sticks was nearly eight feet. We have now about three acres planted with these canes, and, if nothing happens, it will be a field that will cheer one's soul in a year hence to gaze upon.

List of Different Varieties of Sugar Cane Grown in Hilea Sugar Plantation, Kau, Hawaii.

1. +*Uala-lehu*—This cane grows well on uplands. Reddish green with a bloom on the joints.
2. +*Uala-maoli*—This cane grows well on uplands. Reddish green with a bloom on the joints.
3. *Palani*—Grows large with but few sticks in the hill. Striped, known in Mauritius as Bourbon cane.
4. *Honuaula*—Fair Red (dark).
5. +*Laukona*—A good eating cane and that is all. White with green stripes.
6. *Kanio*—Hardy cane. Dark red with green stripes.
7. *Lahaina*—This cane was taken to Lahaina by Capt. Pardon Edwards from the Marquesas Islands in a whaleship.
8. *Kokea*—This cane is awaiting the burial service. White. The Lahaina cane has driven this one off the track.
9. *Mikioi*—A good cane. Light red and green stripes.
10. *Hou*—A good cane. Light red and yellow stripes.
11. *Ainakea-haiili*—One of our best canes. Dark red and green stripes. Meat white.
12. *Ainakea-maoli*—One of our best canes. Light and green stripes. Meat white.
13. +*Pupa*—Of little account. Dark red—short jointed.
14. *Manulele*—Fair quality. Purple and brown stripes.
15. *Apeape*—Fair quality. Light green with dark green stripes.
16. *Puaole*—A poor cane with us. Dull red and purple stripes.
17. *Ohia*—A good cane, dark red, the meat inside is white.
18. *Irwini*—A hardy cane. Like the Hou, but has larger joints and darker leaves.
19. *China* or *Cuban*—Yields well on rich moist land. White—came from Tahiti.

We have also seventeen varieties of cane from Mauritius, but as the labels got mixed we are unable to give them their proper names. Three of these canes, viz.: two white and one striped grow well and ratoon well.

Rose Bamboo—from Queensland. Rose color, with joints from 6 to 8 inches long.

Big Elephant—from Queensland. Dark red with light green joints.

Otaheate—from Queensland. This cane is blood red, and white on the inside, with long joints.

Green Caledonia—from Queensland. White.

All the canes from Queensland are growing here exceedingly well.

Canes in the list marked with a (+) are indigenous to these islands.

Mr. Spencer's statement as to the date of arrival of the Queensland canes at Hilea agrees with that of Mr. Davies. From this evidence it may be concluded that Yellow Caledonia, Rose Bamboo, Big Ribbon, Elephant and Ottmatie (Otaheate) were imported from Queensland by Mr. Turton in 1880 or 1881 and that cuttings of these varieties with the possible exception of Big Ribbon were forwarded to Mr. Spencer at Hilea by W. G. Irwin and Company in July 1884.

Second Importation from Australia

Information concerning a second importation from Australia is to be found in a letter from R. A. Macfie, Manager of Kilauea Sugar Plantation to the Chairman of the Committee on Varieties of Cane. This letter is incorporated in the report of the Committee (23, p. 198) for 1885.

In 1882, we obtained from Australia some seeds of the varieties known there as the Black Java, Meera, and Oboe. Since that date, I have grown these varieties alongside the Lahaina cane, both in poor soil with bone meal, and on good soil without manure. On poor soil none of the varieties have grown as well as the Lahaina cane,

but on the good soil they have done better, and equal Lahaina in number of stalks per stool, and in length of joints; the stalks, however, are smaller than those of the Lahaina. I am sorry that I cannot give any comparison of density or polarization of juice which would be of value. Nor can I pronounce a decided opinion as to which of these varieties has done best; but perhaps the meera stools have done better than the others. We have not had any "Elephant" cane growing here.

Subsequent Importations

A number of new varieties from abroad made their appearance during the ensuing years. However, details concerning the sources of these importations and their dates of arrival are lacking.

Dr. Walter Maxwell (16, p. 16), the first Director of this Experiment Station, lists in his annual report for 1898 the varieties under test at that time. The list includes the following eight canes to which no previous reference can be found.

Fiji Purple	Louisiana Purple
Striped Singapore	Demerara 95
Tibboo Mird	Demerara 117
Louisiana Striped	Demerara 124

The annual report of the Station for 1902 contains a discussion of varieties by C. F. Eckart (6, p. 9) which reads:

Of the four new varieties of cane harvested this year at the Experiment Station two of them, White Bamboo and Demerara No. 74, are extremely promising.

Otaheite and Salangore . . . gave but small returns of sugar per acre and showed no favorable characteristics that would recommend them for further trial.

In his annual report for 1903, Mr. Eckart (7, p. 22) reports the harvesting results from a list of 21 varieties including the following nine canes to which no previous reference has been found.

Queensland 1	Bongan
Queensland 4	Badila
Queensland 7	Gee Gow
Queensland 8-A	Cavengerie
Sacuri	

We find in the annual report for 1904 the following statement by the Experiment Station Committee (9, p. 272):

The Director of the Station has been in communication with Dr. Maxwell in connection with new varieties of seed cane and with the approval of the Board of Trustees has arranged with that gentleman to have a few new Queensland varieties introduced here, the canes, however, being subject to the examination of Entomologists Koebele and Perkins (now in Queensland) previous to shipment, and by Mr. Craw, the local Government entomologist and inspector, upon their arrival here. These precautions have to be taken with all canes intended for introduction here, owing to numerous insect pests and fungus diseases which are prevalent in other countries but which are fortunately not yet in this country.

Mr. Eckart's (5, pp. 287-288) report for 1904 contains this statement.

New varieties of cane planted this year are as follows:

Striped Tip	Demerara No. 1937
Daniel Dupont	Queensland B. 5
Demerara No. 115	Queensland B. 8A
Demerara No. 116	Queensland B. 147
Demerara No. 145	Queensland B. 156
Demerara No. 1135	Queensland B. 176
Demerara No. 1483	Queensland B. 208
Unknown	Queensland B. 244
Dark Colored Bamboo	Queensland B. 306
Moirs White	Altamatti

Of these new varieties, Moirs White, a 'sport' from Big Ribbon is at the present time making the best showing, having produced a marvelous growth since planting during the latter part of June and indicating the value of carefully testing the merits of such sports as emanate from well known canes of little repute.

In the Annual Report of the Experiment Station Committee (10, pp. 81-82) for 1905 we find the following:

New Varieties Received. On April 5th, 1905, ten new varieties of cane were received from Fiji in care of Prof. A. Koebele, who had obtained the same from Mr. James Clark of Rarawai Mill. These canes were labelled as follows:

Badila	White Tanna
Couve No. 27	Goru
Malagache	Hitam
Hybrid Footiogoo	Bonbari
Innis 131	Petit Senneville

On their arrival in Honolulu, these varieties were carefully disinfected by Mr. Alexander Craw and examined by Messrs. Craw, Koebele and Perkins, and by Dr. Cobb, in order that no insect and fungus pests might be introduced into this country from Fiji. After passing through the hands of the plant pathologists and entomologists, the cuttings were planted in the special insect-proof cane propagation house of the station in order that seed cane might be obtained for propagating the varieties in the field. Unfortunately, of these canes, only four germinated, viz:

(1) Couve 27
(2) Badila
(3) Hybrid Footiogoo
(4) Innis 131

These varieties will be added to the list of those undergoing trial in the Experiment Station field and as soon as sufficient cuttings are available for plat experiments, will be brought into competition with the older canes.

It is believed that the four survivors were later destroyed since no mention is made of them in subsequent reports.

Decline of Lahaina

Toward the end of the nineteenth century the old Lahaina variety began to succumb to a mysterious root disease. Even in the fields in which it had once produced excellent crops the yields declined alarmingly. As time went on it became increasingly evident that a substitute for Lahaina would have to be found. Yellow Caledonia was resorted to as a temporary replacement but it was recognized

that this cane was not well suited to the climatic districts in which Lahaina had once produced such excellent yields.

At this point a second catastrophe descended upon the industry. A sugar-cane leaf hopper had somehow gained entrance into the Islands, possibly in one of the several importations of cuttings from Australia. Having established itself in Hawaii in the absence of its natural parasites this leaf hopper began to multiply at a prodigious rate. Its ravages caused sugar yields to decline still further, and many fields were all but ruined.

Thoroughly alarmed at the seriousness of the leaf-hopper threat and impressed with the possible danger from further diseases and insect pests which might accompany importations of sugar-cane cuttings from foreign countries, the planters were instrumental in the enactment in 1904 of a regulation by the Board of Commissioners of Agriculture and Forestry prohibiting the "introduction of all sugar cane into the Hawaiian Islands save and excepting small quantities of special varieties for purposes of seed and these shall be imported through the port of Honolulu only and shall also be subject to the special treatment and supervision of the entomologists, on arrival."

The leaf hopper continued to be a serious pest until it was finally brought under control by parasites introduced from other countries by the Station entomologists, but that is another story.

Beginning of Sugar-Cane Breeding

In 1858 J. W. Parris of Highland Plantation, Barbados, succeeded in growing to maturity some seedling sugar canes which had appeared as volunteers in one of his fields. An account by Mr. Parris (14) of the circumstances surrounding this accomplishment appeared in a local newspaper, the Barbados *Liberal* on February 12, 1859.

> Mr. J. W. Parris, to the Editor of *The Liberal*.—
>
> In accordance with your request, I now send you the following particulars regarding the canes established from the seed, and which are now growing on Highland Plantation.
>
> I think it was somewhere in the month of May last year, that my attention was called to the fact of there being several cane plants growing in a field of ratoons, which the Superintendent pronounced as having grown from the seed of the cane arrow. On first examination, I thought it was a mistake, they bore so close a resemblance to guinea grass when it grows from seed; but as there was not any of this kind of grass growing on or near the field in question, I could not account for its presence there, and this circumstance caused a stricter examination on my part, the Superintendent all the while declaring positively that they were veritable canes. After being satisfied myself that they were really canes, I caused all that could be found to be removed and transplanted to another field, but in consequence of the weather being very dry I could only save seven plants of them, and these are now alive and are growing. I intend having the plants from those put in a spot by themselves this year, hoping to obtain seed from them again.
>
> The field on which they grew is in that part of the estate which runs down a hill into Scotland; the soil is very moist and is composed of clay, siliceous sand, and chalk, and had been the year previous thoroughly tilled and was in what we planters call fine heart, that is in a finely divided and pulverised state. The parent canes were very vigorous, and there were several varieties growing together in the field. It appears

as if there are seed from three kinds growing—the Bourbon, Transparent, and Native; that is the plants which are growing have the appearance of these at present. I would also remark that these plants were not found growing in one spot but were scattered over a space of more than half an acre, and grew up wherever the trash did not cover the land thickly. Any further information that you or any other gentleman might require concerning the above, I shall be most happy to afford, as far as I am able, or to shew the plants as they now stand.—Glendale, February 8th, 1859.

Unfortunately none of the seedlings proved equal to the parent varieties; they were eventually discarded and Mr. Parris' achievement was forgotten. Learned professors of botany continued to teach their students that long-continued propagation by cuttings had deprived sugar cane of its capacity for sexual reproduction.

In 1885 Dr. F. Soltwedel (15) working in Java began a study of the reproductive organs in *Saccharum*. He found the pollen of *S. spontaneum* to be normal in appearance. He ascertained further that this pollen was capable of fertilizing flowers of the same species and he succeeded in germinating seedlings from *spontaneum* seed. In 1887 he germinated and grew to maturity seedlings germinated from tassels of a variety known in Java as "Hawaiian Cane."

In January 1888 Mr. J. B. Pilgrim (14, pp. 260-266), an overseer at Dodds, Barbados, observed what later proved to be young sugar-cane seedlings volunteering in the neighborhood of one of the experimental fields in which a number of different varieties were growing. He brought these volunteers to the attention of Professor J. B. Harrison, the Colonial analytical chemist, and John Bovell, the manager of Dodds, who transplanted some sixty of these seedlings for further observation. The individuals which reached maturity were spread further by means of cuttings.

Fig. 1. The birthplace of H 109. The offices and laboratories of the Experiment Station, H.S.P.A. in 1905.

In January 1889 Harrison and Bovell obtained germinations from field-collected sugar-cane seed which they had sown in boxes.

Thus from opposite sides of the globe came evidence to refute the "sterility" myth which had for so long held sway in botanical circles. Sugar-cane breeding was soon under way in earnest in both Java and Barbados. Demerara and Martinique followed suit. The progress of these projects was followed with interest throughout the sugar world.

Beginning of Sugar-Cane Breeding in Hawaii

In 1900 R. E. Blouin who was then director of the Station made an unsuccessful attempt to grow sugar-cane seedlings from ripe tassels of Lahaina and Rose Bamboo. Mr. Eckart (8) reported October 12, 1907 that " . . . some of the seeds were covered and others were not covered; none of them germinated, however."

By the beginning of the present century Luther Burbank had become widely known as a plant breeder. In January 1904 the planters sought through representatives in San Francisco to enlist Mr. Burbank's aid in initiating a sugar-cane breeding program in Hawaii. Mr. Burbank's (2) reply reads as follows:

Santa Rosa, California,
Jan. 17, 1904

Mr. R. D. Silliman,
San Francisco, Cal.

My dear Sir:—

Your esteemed letter of January 12th was received in due season, but I have been extremely busy of late and unable to keep up my correspondence. The time, thought, correspondence and labor necessary to produce the Sugar Cane having the characteristics which you desire would necessarily take me from many other lines of important work which are well carried forward towards completion, and which have involved the expenditure of many years and a vast amount of capital. I hardly see how I could take up this extra work, though I have appreciated for years the fact that the sugar cane was perhaps one of the most, if not the most important plant which one could work upon for improvement, and this must be done soon, as it has already in most countries lost the power to produce true seed. When this habit is once thoroughly fixed, no power on earth could improve it to any great extent.

I have had so-called Sugar cane "*seed*" repeatedly sent me from various countries, but in every case it has proved to be *without a germ*. With a pound of good seed I could raise ten thousand new varieties even in California. These could be shipped to some more suitable climate and tested on a comparatively small piece of land. This is the only main way which the Sugar Cane can ever be improved upon, but even this requires most careful attention, and a knowledge of the characteristics of plants possessed but by very few people inhabiting the earth at present.

It would not be a difficult matter for me to produce a Sugar Cane with much more sugar, and to partially or wholly remove the husk by breeding. I shall be glad to be of any aid to the planters in this line which my experience had given me, and thank you for promises of assistance and information in regard to matters connected with the Hawaiian Islands.

I am now working on nearly half the plants ever cultivated by man, and really have more business on hand now in that line than a hundred and fifty men should have. However, the improvement of the Sugar Cane is of vast importance, and I may be able to furnish plans on which the work should be carried forward for these desired improvements.

Very respectfully yours,
(s) Luther Burbank.

Mr. Silliman subsequently conferred personally with Mr. Burbank, who offered suggestions "for the improvement of sugar cane" which Mr. Silliman (22) recorded in the following letter.

San Francisco, May 23, 1904.

Mr. John A. Buck,
327 Market Street,
City.

Dear Mr. Buck:

In pursuance of our conversation this morning, I beg to give you the substance of the suggestions made by Mr. Luther Burbank for the improvement of sugar-cane.

The first thing to be done is to procure seedlings. To do this, it may be necessary to plant a great quantity of seed before any shoots can be had, as sugar-cane has, to a large extent, lost the power of producing vital seed. It is said, however, that seed is effectually planted in Jamaica and also in British Guiana. Mr. Burbank is very confident that if it is gone about in the proper way, seedlings can be raised from seed taken from cane in the Hawaiian Islands, but he thinks it would be necessary to take large quantities of the seed and plant them in such a way as will be most likely to cause the shoots to grow; to use his own expression, it would probably be necessary to "tease them (the seedlings) into growing."

The seeds should be planted in shallow boxes, say 2½ feet long by 1½ feet wide and three inches deep; the bottom of the box should have slits in it so that the water may the more readily drain out. The first layer in the box should be broken traprock, if the experiment is conducted here, or broken lava if in the Islands. This gravel base should be made up of pieces about the size of a pea. Above this, rough edged sand should be used if possible. (The *smooth,* coral sand of the Islands is not desirable, but coral sand itself would be very good if the edges of the sand have not been worn smooth by the action of water.) Above the sand, and as a final surface soil, should be used a mixture of sand and sifted moss or pulverized peat. This should be laid in to a depth of about one inch over the sand, then the pulverized tassel containing the seeds should be laid in to a thickness of say half an inch, and above this, another covering of the sifted moss or pulverized peat should be added. This should be thick enough to thoroughly cover the seed, say half an inch. The tassels should be taken just as they are fully mature, that is, just about as they are beginning to fall. The seed cannot come up too thick. The pulverized tassel decomposes and forms part of the bed in which the seeds grow. (The purpose in planting so large a quantity of seed, is to have the greatest number of chances of some sprouting.) A number of boxes should be used in this way. These boxes should be kept in a green house; the temperature should be from 65 to 100°. (Mr. Burbank said that the green house should be closed so that there will not be a draught through it. I do not know, however, as this will be necessary in the construction of a green house in the Islands where the temperature is so uniform.) The seed should be watered once a day thoroughly, and the seedlings should be kept well watered also, but not too often; they do not want to be "petted," sprinkled or otherwise fussed with.

After the seedlings once begin to grow, Mr. Burbank said he would then give us further assistance by way of suggestion in selecting from them; he did however, go on to say that as soon as the seedlings were an inch or so out of the ground, they ought to be set out about two or three inches apart, and thereafter when the seedlings have grown to the height of, say four or five inches, they ought to be again transplanted four inches or so apart, and then after they have grown a little more, they should be set out into the ground. When the seedlings have matured, which will be in about three years' time, they ought to be chemically tested to ascertain which of them contains the greater amount of sugar, and the seed of those which contains the greater amounts of sugar should be used for re-seeding; all the rest should be discarded. Another point insisted upon by Mr. Burbank, was that it is very desirable, if possible

to get seed from different countries and locations and cross the same, as this produces a cane some of the seedlings of which will have greater vigor than any of their parents, and will be more likely to contain a larger quantity of sucrose content. The whole basis of improvement lies principally in variation and selection. You keep the best and discard all of the remaining. He declared that the sugar-cane belonged to a family that was much more easily improved than the beets; that naturally the cane ought easily to displace the beet as a rival in the production of sugar, but the reason why the beet has made such progress and inroads upon the market, is because of the greater attention given to increasing its saccharine matter. The sugar of the beet has been increased fourfold or more in the last fifty years, while there has been no material advance in this respect in cane. He declared that the sugar of cane ought to be doubled in a few years' time.

Mr. Burbank also suggested that it would be advisable to procure the co-operation of the Department of Agriculture at Washington, especially in procuring vital seed. He thought that they would be in a position to procure good seed more easily than any of us. He also assured us that he would be very glad to answer any further questions that we might wish to ask of him in writing or otherwise.

I would be very glad to try and arrange for a visit to Santa Rosa. Mr. Burbank's time is greatly taken up, but I am satisfied that I could arrange for you to go down there and see the work that he has done and have a talk with him.

I enclose herewith a copy of a letter from Mr. Burbank to myself written the first of this year.

Yours very truly,

(s) R. D. Silliman.

Mr. Burbank's suggestion in regard to enlisting the cooperation of the Department of Agriculture was evidently acted upon, for we read in the Annual Report (10, p. 83) for 1905 that "Through the kindness of the U. S. Department of Agriculture and the Imperial Department of Agriculture for the West Indies, three small consignments of pulverized cane tassels were received from Barbados, Jamaica and Trinidad." The first sowing of this seed was made on December 21, 1904, the last on February 24, 1905. From these imported tassels 812 seedlings germinated, of which 279 survived and were transplanted to the field. Seed from

Fig. 2. The area behind the laboratories at Makiki where sugar-cane breeding in Hawaii began in 1905.

locally grown tassels were also sown, but only a single seedling germinated and that from a tassel of Demerara 74 sent by H. A. Baldwin from Maui.

In December 1905 the Experiment Station was successful in germinating 5608 seedlings from tassels collected from the variety collection growing in the Station plots at Makiki. These seedlings were transplanted first to pots and in April 1906, the 5232 survivors which by this time had grown to a height of a foot or more were transplanted to the open field.

In April 1907, 15 months after germination, the seedlings were examined one by one, and permanent numbers were assigned to the 355 which appeared promising enough to merit further testing. The numbers H 1, H 2, H 3, etc., to H 399 were assigned to the individuals thus selected (omitting those numbers assigned to the seedlings germinated in 1904-1905).

At this point the lack of adequate area for the testing of these selected seedlings began to make itself felt. Except for the plot adjoining its headquarters at Makiki the Station had no land at its disposal. It became necessary therefore to pass on to the plantations the task of testing these new canes to determine their possibilities as commercial varieties in the various climatic districts.

The Rise of H 109

In 1907 cuttings of some of the more promising seedlings were distributed to the plantations. Only a small amount of seed of each seedling was available at this stage; a given seedling could be distributed to only a few plantations. In this first distribution H 109 was sent to two plantations, viz., Waialua Agricultural Company and Hawaiian Agricultural Company.

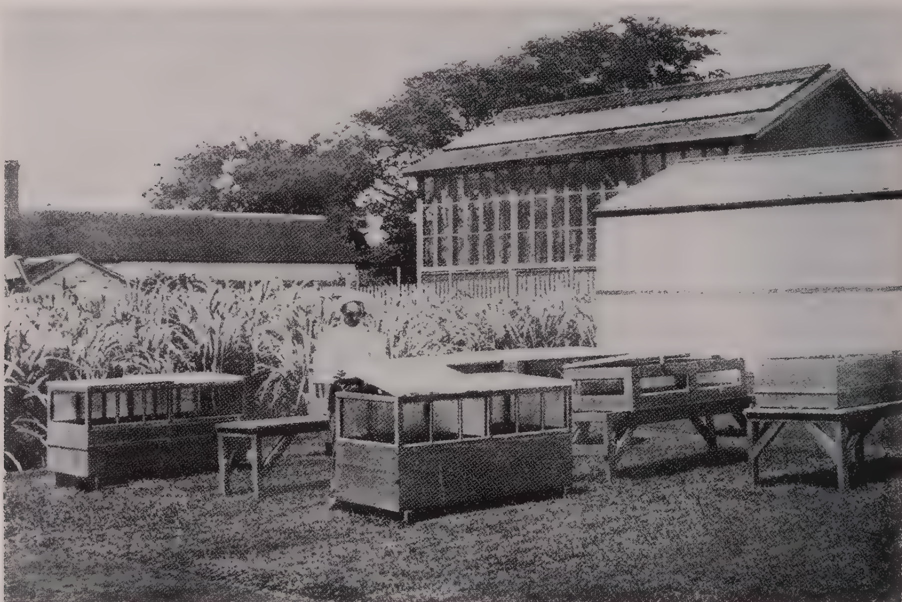

Fig. 3. Houses and boxes used in growing sugar cane from seed.

In 1908, H 109 was sent to three more plantations, Niulii, Union Mill and Kihei Sugar Company. In 1909, H 109 was sent, along with a number of other seedlings to ten plantations. In 1910, twenty-three additional plantations received seed of H 109.

In these early years of testing H 109 attracted some favorable comment but its potentialities were not generally recognized. For several years certain other seedlings, which were more spectacular in appearance than H 109, held the spotlight. H 20, H 27, H 146, H 227 and H 333 were among the early favorites.

In the course of time however the evidence from trial plantings began to focus attention upon H 109. In the Annual Report of the Experiment Station Committee (11, p. 37) for 1912 we find the following:

> The results of preliminary tests have in several instances been reported, . . .
> These preliminary tests seem to place special emphasis upon H 27, H 109 and H 333.

In the Annual Report (12, p. 24) for 1914 we read that " . . . H 109 gives especially good promise."

Ewa Plantation Company led the way in spreading H 109 to field-scale plantings. By 1915 Ewa had planted over a thousand acres of H 109. Oahu Sugar Company came second with 373 acres.

The popularity of H 109 rose rapidly as the harvesting results from these early field plantings began to come in. In some cases new yield records for the field were established. It became increasingly evident that for the leeward irrigated lands H 109 was a better variety than either Lahaina or Yellow Caledonia.

The rise of H 109 and the decline of Lahaina and Yellow Caledonia may be seen in the following figures:

	Acres harvested		
Combined crops of	H 109	Lahaina	Yellow Caledonia
1913-1914	26	80,905	116,490
1915-1916	597	72,459	112,241
1917-1918	3,928	65,474	115,695
1919-1920	11,889	53,679	108,292
1921-1922	30,578	32,617	107,588
1923-1924	52,487	13,486	93,499
1925-1926	79,675	5,809	79,622
1927-1928	103,680	2,704	67,865
1929-1930	114,851	1,008	58,600

Expansion of the Breeding Program

From 1906 to 1912 only a few hundred new seedlings were propagated. Apparently the interest and the facilities of the Station and the plantations were fully occupied with the task of testing the promising canes of the 1905 group.

The shortage of area for the preliminary testing of seedlings was partially relieved in 1912 following the establishment of the Waipio substation. In 1913 seedling propagation was resumed and 3684 seedlings were grown. From that time to the present, each year has seen the propagation of at least a few hundred seedlings. A new high in seedling propagation was established in 1919 with 21,664 seedlings and again in 1920 with 42,042 seedlings.

Several of the seedlings propagated during this period attained the status of commercial varieties on limited areas. H 456, propagated in 1913 from tassels of H 240 served as a substitute variety on more than a thousand acres from which

H 109 had been dislodged by severe attacks of eyespot disease. Kohala 107, a seedling of D 1135, propagated at Kohala Sugar Company in 1917 rose to an area of nearly four thousand acres in the lower lands of the Kohala district. A sister cane, Kohala 202 was spread to thirty-five hundred acres, localized for the most part in the middle-belt lands of Kohala and Windward Kauai.

However, as time went on it became increasingly evident that further progress was not to be easily achieved and that new angles of attack would have to be explored. A need for new breeding material was keenly felt. More efficient crossing and nursery techniques were urgently desired. And finally, it was recognized that for the prompt and thorough testing of large numbers of new seedlings more adequate testing facilities would have to be provided.

The measures which were taken to meet these needs will be examined in the following chapter.

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A Search for Guidance in the Nitrogen Fertilization of the Sugar Cane Crop

Part III—The Second Ratoon Crop

By R. J. Borden

The third and final series of measurements and analyses made from representative samples of a crop of 32-8560 ratoons from our Waipio Experiment 108 ATN have added to our knowledge of effects which nitrogen fertilization may be expected to produce on sugar cane. Verification has been secured for many of the effects which were indicated in previous crops, and undoubtedly we are somewhat nearer to the principal objective which we set up when these cooperative nitrogen studies were started; this objective has been to secure guidance in the use of nitrogen fertilizer for sugar cane crops.

Contents

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Introduction

In our search for guidance in nitrogen fertilization for the sugar cane crop, we have previously reported* many measurements and analyses made from samples of the plant and the first ratoon crops of 32-8560 cane grown at Waipio in Experiment 108 ATN, and we can now add the corresponding data which have been secured from the second ratoon crop.

The Plan and Procedure

1. The Plan:

The same experimental area, which has been previously described, has furnished the cane samples which were again taken at the ages of 3½, 5½, 7½, 8½, 9½, 10½, 11½, 14½, 17½ and 20½ months. These samples consisted of *all* cane stalks cut from a previously designated solid stand in eight scattered five-foot sections of cane row.

After the field harvest of the first ratoon crop, which took place during very unfavorable rainy weather, this second ratoon was officially started on March 25, 1944. The plan of fertilization was similar to that used for the two previous crops—specifically as follows:

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* Borden, R. J., 1942. A search for guidance in the nitrogen fertilization of the sugar cane crop. Part I—The plant crop. The Hawaiian Planters' Record, 46: 191-238.

————, 1944. A search for guidance in the nitrogen fertilization of the sugar cane crop. Part II—The first ratoon crop. The Hawaiian Planters' Record, 48: 271-306.

Plot Identity	No. of Plots	2½ Mos. Appl. #1 6/10/44 Lbs. N	4 Mos. Appl. #2 7/17/44 Lbs. N	Lbs. K20	6 Mos. Appl. #3 9/18/44 Lbs. N	11 Mos. Appl. #4 2/19/45 Lbs. N	Totals N	P205	K20
A	8	40	60	100	0	0	100	0	100
B	8	40	60	100	0	60	160	0	100
C	8	40	60	100	60	0	160	0	100
D	8	40	60	100	60	60	220	0	100

The same 3 "X" plots which had received no nitrogen for their plant or first ratoon crops were included for another crop without nitrogen fertilization.

A total of 27 irrigations, at intervals of approximately 250 day-degrees, was given until October 11, 1945 when irrigation was stopped. Between this date and the final harvest of the field there were 17.1 inches of rain, 6.3 inches of which occurred during the harvesting period. Hence, it was impossible to secure any effective "drying off" and the crop was making good growth when its final field harvest took place at 23 months.

2. Observations and Comments at Periodic Harvests:

At 2½ months: This second ratoon crop got off to a very slow start. Wet weather had delayed the ratooning, replanting, and the fertilization, and the new ratoon growth was spotty. No evidence of nitrogen deficiency was observed, even in the leaves of the "X" plots which had already grown two previous crops without nitrogen fertilization. No stalks had as yet made millable cane, although the non-millable stalks averaged better than 13 stalks per foot of row. A possible residual effect from the heavier nitrogen applications to the "D" plots in the previous crop may be suggested by their somewhat higher population of non-millable stalks, but the wide variation in all stalk counts makes it difficult to establish such residual effect with confidence.

At 5½ months: The cane on the "no N" plots is now quite yellow but leaf color elsewhere is quite satisfactory. Recent cane growth has been very rapid and the field now begins to look less spotty.

At 7½ months: The field is now well "covered in" and there are 5 to 6 millable stalks per foot of row although many of them are still quite short. The leaves of the C and D plots which received nitrogen fertilizer two months ago are darker green in color than leaves from the A and B plots which did not get this extra nitrogen application. There are still many small non-millable stalks in plots of all treatments.

At 8½ months: The leaf-color differences are still existent. All stalks are still erect. The first dead primary stalks were recorded, apparently being smothered by the heavy leafy top growth. A few small suckers have now started in ten of the plots but there is no evidence that this is a treatment effect.

At 9½ months: Practically all of the non-millable primary stalks have now died, and many millable stalks are recumbent. A few more suckers have started but are still quite small. Leaf-color differences are still apparent with no sign of yellowing in the canes which have had 160 pounds of nitrogen to date (Treatments C and D).

At 10½ months: More primary stalks are now recumbent. The first suckers with millable stalks were taken from the C and D plots which had received the

higher nitrogen applications, and there were many more new non-millable suckers appearing in these plots. Leaves from the C and D plots still held their healthy green color as contrasted with the yellower green of leaves from Treatments A and B which have received only 100 pounds of nitrogen to date.

At 11½ months: Leaf-color differences were not as clear cut in this harvest; the new leaves irrespective of nitrogen treatment appear narrow and short. There are many new non-millable suckers in all plots, and still more suckers with millable stalk in Treatments C and D. There are still 4 to 5 millable primary stalks per foot of row although there has been a high mortality of these stalks since the previous harvest; there is no apparent cause of this dead cane. For the first time, the millable canes are now definitely sweet to taste.

At 14½ months: Only Treatment D now has a good green leaf color. Millable suckers have increased in all treatments and the larger suckers now weigh almost as much as the primaries. The "no-N" plots show their first evidence of suckers with millable cane. About 20 per cent of the original primary stalks which had made millable stalks are dead, but this mortality is not necessarily confined to any specific nitrogen treatment, except that it is definitely lower in the "no-N" plots in which the cane growth is very much retarded. Considerable variation is again apparent between replicates.

At 17½ months: Treatment D still has a good leaf color. For some unknown reason treatment X has "greened up" and made a new spurt in its growth. The numbers of millable suckers continue to increase and they now amount to about 35 per cent of the total millable canes. Mortality of primaries has increased to as much as 25 per cent in the C and D plots; some of this mortality is due to "splits" in the stalks. In general the canes appear to be heavy but they are not especially sweet.

At 20½ months: There are still many dead stalks in Treatment D. The total number of millable stalks has now decreased to not more than 4 per foot of row, and more than 40 per cent of these are suckers which got started about 12 months ago. A few of these suckers have died but most of them are still erect and carry healthy green tops, and they are contributing heavily to the total cane tonnage being produced.

3. Experimental Procedure:

Each month while this second ratoon crop was developing, soil samples were again taken to a depth of one foot from the row middles of a series of X and D plots, and tested by our Mitscherlich test for available nitrogen. Leaf-punch samples for nitrogen analyses were also taken from each plot at monthly intervals.

The cane samples for each harvest were taken in a way to insure their being truly representative of the whole field crop. Weights which were secured are reported on their equivalent tons per acre (net area) basis. Duplicate cane samples were made up on the basis of the stalk census which was taken at each harvest. One of these samples was milled in the Waipio Cuban A mill, and the duplicate was prepared for the various laboratory analyses.

All measurements and analyses from the eight replicates, in the 32 plots which received nitrogen fertilizer, were studied by "analysis of variance" to determine their statistical significance.

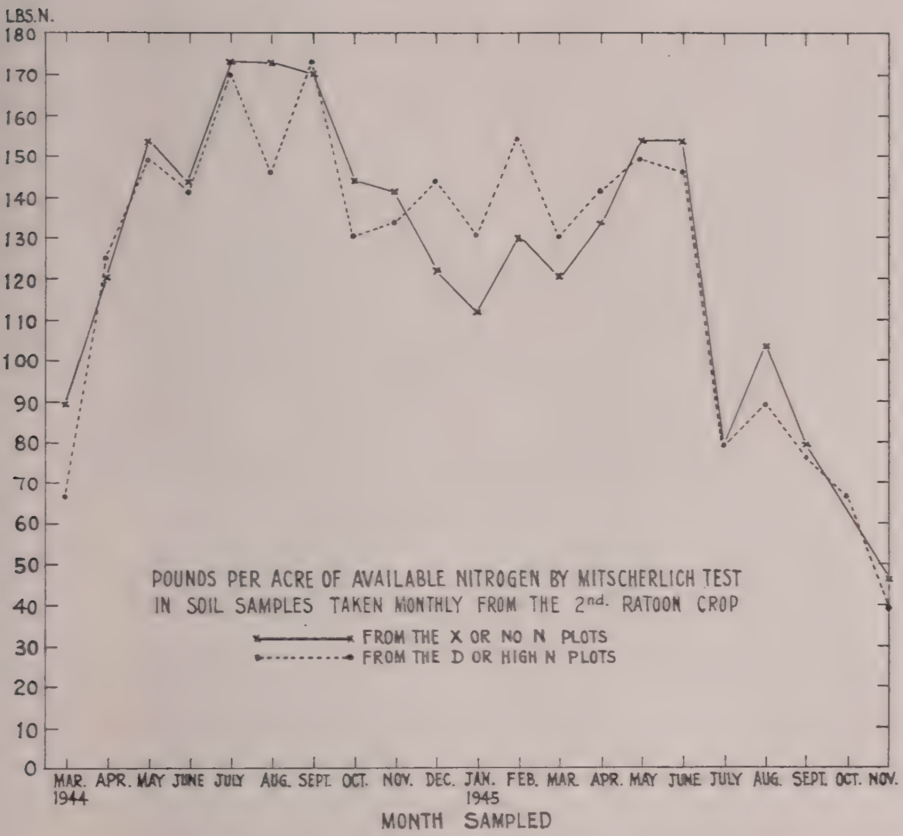

Fig. 1.

4. Monthly Soil Analyses (Fig. 1):

Once again the monthly soil samples, as taken from the row middles of both the "no-nitrogen" and "high-nitrogen" plots, show the progressive changes which are continually taking place in the available nitrogen supply of a soil that is carrying a crop of cane. During the first few months, while the crop was slow in getting underway, the available soil nitrogen increased steadily and in July 1944 it had reached the highest amount (173 pounds per acre) that had been recorded in this soil since it was plowed some four years previously. This high natural nitrogen supply was maintained for several months, and it was nicely reflected in the greatly accelerated cane growth that was being made. As the field "covered in" and the cane roots reached this source of nitrogen, the amounts found were somewhat less than those found earlier, but they were still maintained at a relatively high level (above 100 pounds per acre) during the first winter season. Another increase started early in the spring of the second season and continued through June; its effect on the increased number of suckers was clearly noted in the June and September harvests. But following the June samples, there was a very abrupt drop in this available nitrogen supply and the low point was reached in the field samples taken just before the final harvest.

In general the available nitrogen released from the natural supplies in this soil was at a considerably higher level throughout the greater part of the growing period of this crop than it had been in the two previous crops, and it is not unlikely that this fact has some positive relationship to the poorer cane quality that was found in this second ratoon crop at its final harvest.

Treatment Effects

1. Their Reliability:

The extreme variability in field measurements from small samples of cane makes it difficult to secure acceptable statistical significance for the differences in many of the measurements secured, even though 8 replicates were available. Still it is not necessarily incorrect to make a careful rationalization of the available data and, with past experience for guidance, to arrive then at logical interpretations.

The relatively low coefficients of variation that were found for such measurements as (1) per cent moisture and per cent fiber in the total green weight, (2) per cent sucrose and total sugars in the total dry weight after the crop reaches an age of 9 or 10 months, (3) per cent nitrogen in samples from specific green-leaf blades, and (4) per cent moisture in leaf sheaths, indicate a considerable degree of uniformity in such components of the crop. On the other hand, the high coefficients associated with (1) all cane weights and other measurements which are dependent on cane weights, (2) the percentage of reducing sugars in the total dry weight, (3) the percentages of sucrose and of total sugars in the young cane, (4) the percentages

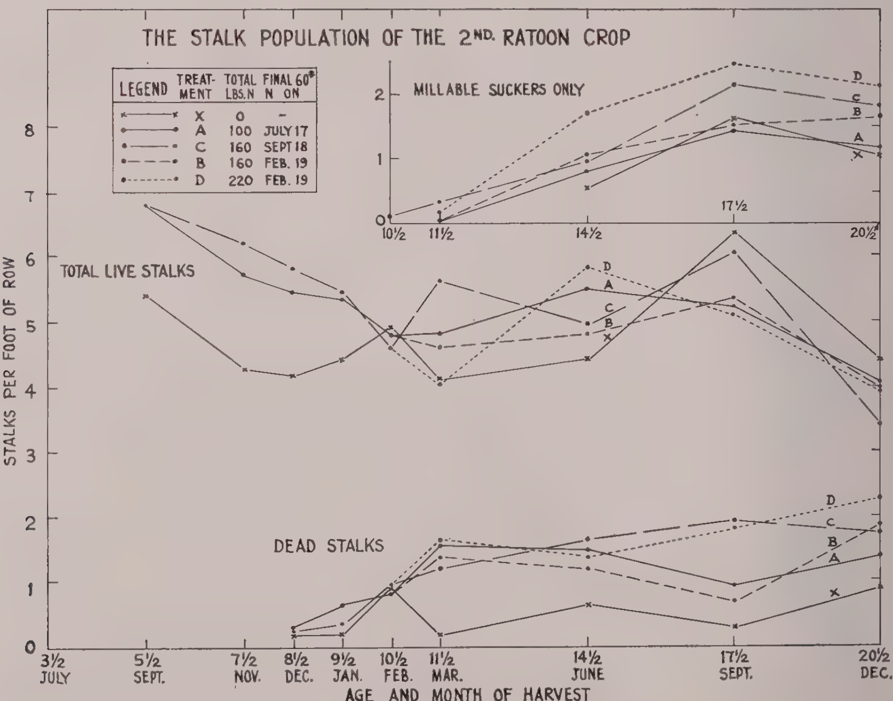

Fig. 2.

of nitrogen, phosphoric acid, and potash in the total dry weight, and also the nitrogen in the crusher juices, and (5) the percentage of total sugars in the leaf sheaths at some of the harvests, indicate considerable variability between replicate samples in these measurements, and make our interpretation of differences more subject to error.

2. On the Stalk Population (Fig. 2):

The periodic stalk census shows the major changes which were taking place in the stalk population while the crop was being grown. In general there is a positive effect of nitrogen. The total number of live stalks with millable cane during the first year of growth was greater in the higher nitrogen treatments, but this same relationship was not clear during the second year of growth; perhaps this suggests a greater influence of some other factor than nitrogen during the later growth stages.

The effect of increased nitrogen on the number of millable suckers and of dead stalks is quite nicely shown at the last three harvests. The additional 60 pounds of nitrogen given in February to Treatment B increased its number of suckers over Treatment A which had received only 100 pounds of N, and apparently checked some of the stalk mortality. A similar effect was also recorded from a 60-pound application in February to Treatment D over Treatment C which had already received 160 pounds. However, by the time of the last harvest at 20½ months, these 60-pound increases in nitrogen that had been given at 11 months in February had increased the number of both millable suckers and dead stalks.

The actual number of dead stalks at 20½ months was once more about one-

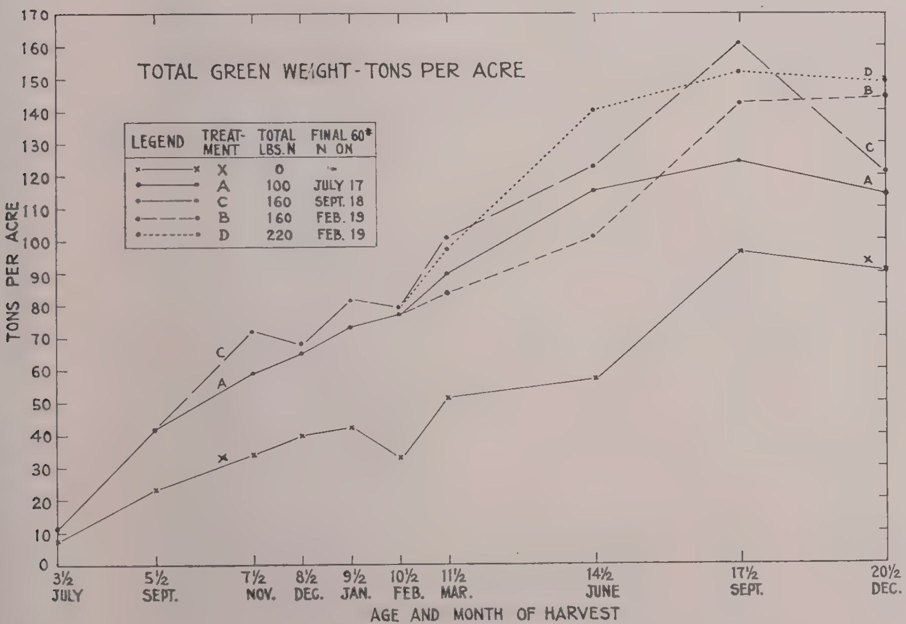

Fig. 3.

third of the total number of canes which had made millable stalk, and 40 per cent of the stalk population at 20½ months was made up of millable sucker growth.

3. On Total Green Weight (Fig. 3) (Table 1 in Appendix):

Total green weight was increased as the nitrogen fertilizer applications were increased, and the relationship between Treatments C, A and X, which received their nitrogen differential within 6 months after starting the crop, was consistent at all harvests. The B and D plots which received an extra 60 pounds of nitrogen in February were slow to show its effect but eventually came through with higher total green weights than the A and C plots respectively.

Excluding the X plots, which received no nitrogen fertilizer, the other 32 plots averaged quite a uniform rate of increase in total green weight for 17½ months and then this increase dropped off sharply. During the first 5½ months the increase in total green weight averaged 7.8 tons per month. Thereafter the gains during successive 3-month periods were as follows:

Between Sept.-Dec.—at 5½ to 8½ months—8.0 tons per month
" Dec.-Mar.—At 8½ to 11½ months—8.9 tons per month
" Mar.-June—At 11½ to 14½ months—9.1 tons per month
" June-Sept.—At 14½ to 17½ months—8.2 tons per month
" Sept.-Dec.—At 17½ to 20½ months—a loss of 4.2 tons per month.

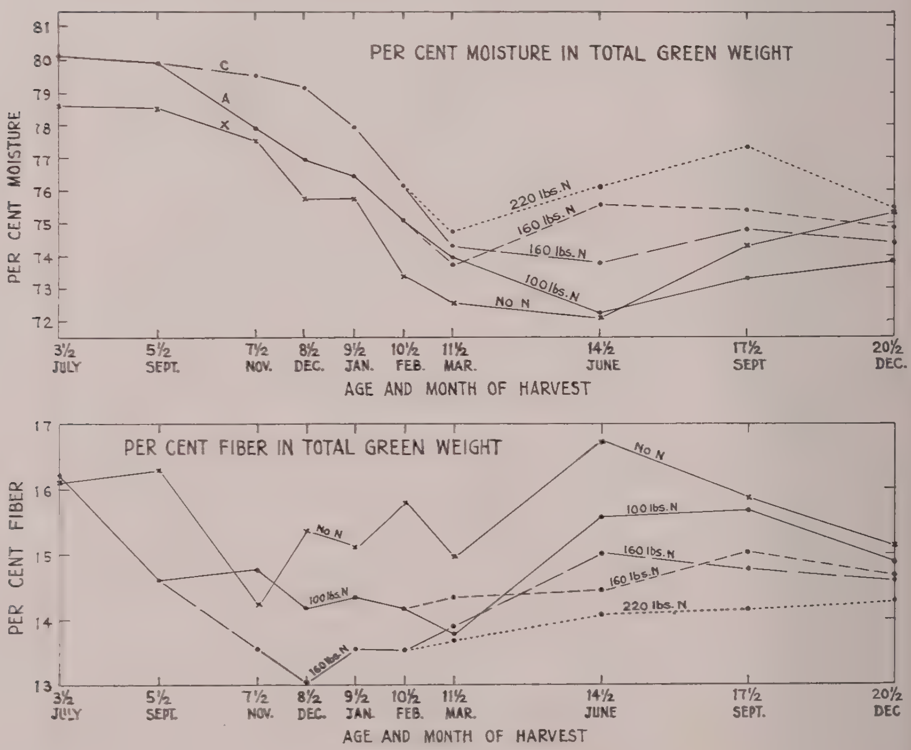

Fig. 4.

4. On Percentage of Tops (Table 2 in Appendix):

At 5½ months, 43 per cent of the total green weight was still in the tops, but this percentage figure had dropped to 20 at 10½ months and eventually reached a low of 11 per cent ten months later. The effects of nitrogen on this measurement were not clear cut or consistent, and we shall not attempt to rationalize them.

5. On Per Cent Moisture and Fiber in Total Green Weight (Fig. 4) (Tables 3 and 4 in Appendix):

The inverse relationship of the treatment effects upon the moisture and fiber is seen in Fig. 4. The higher nitrogen applications have produced a crop with a higher moisture and a lower fiber content. During the first 7 or 8 months the higher nitrogen-fertilized cane had a moisture content close to 80 per cent but this decreased sharply to less than 75 per cent during the subsequent 3 or 4 winter months. The February applications of nitrogen to the B and D treatments were reflected in increased moisture percentages thereafter.

The reason for the increased percentage of moisture in Treatment X after 14½ months needs an explanation. We have recorded other differences in measurements and observations that were found at about this same time in these "no-N" plots. Our observational notes tell us that Treatment X had "greened up" and made a new spurt in its growth at 17½ months. The stalk census shows a large increase in total live stalks in these plots at this harvest, and the total green weight made a sharp increase. The periodic soil analyses had shown a high level of soil nitrogen at the time the new growth in these X plots was being initiated, and in subsequent discussions it will be seen that the per cent N in the total dry weight of these X plots, which had been decreasing, now made a slight increase; this nitrogen increase was also found in the leaf-punch samples. All of these factors would indicate that the crop on the X plots did get a fresh supply of nitrogen from the natural supplies in the soil, and so its increased moisture content towards the end of the crop is in reality an effect from this soil nitrogen.

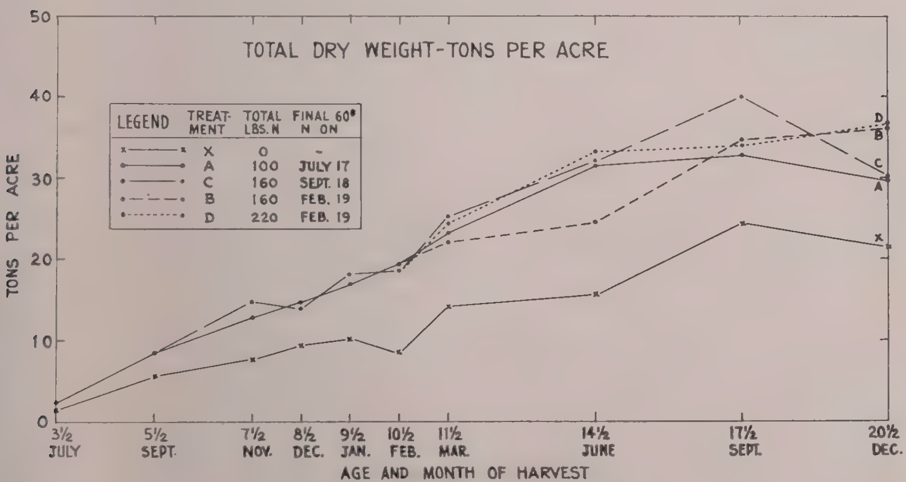

Fig. 5.

6. On Total Dry Weight (Fig 5) (Table 5 in Appendix):

The total dry weight relationship between Treatments C, A and X is not unlike that found for total green weight. All total dry weights show the same steady rate of increase for the first 17½ months that we noted for the total green weights. The high experimental errors for this measurement make it difficult to point out significant differences which can be reliably identified as being the result of the different nitrogen treatments, but Fig. 5 may suggest reasonable trends for extra-

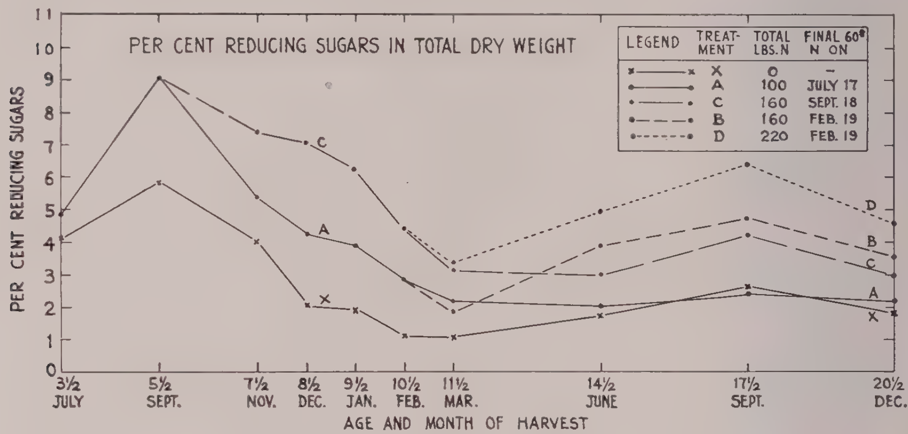

Fig. 6.

polation beyond the points at 20½ months. These could indicate that the February applications of nitrogen to the B and D plots have had a more lasting effect on the total dry weights.

7. On the Composition of the Total Dry Weight:

(a) Per Cent Reducing Sugars (Fig. 6) (Table 6 in Appendix): Each increase in nitrogen application has resulted in an increased concentration of reducing sugars

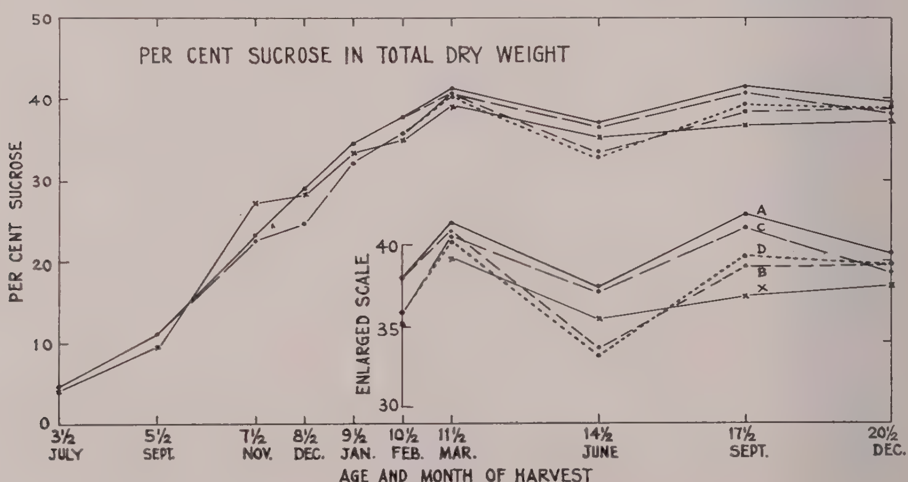

Fig. 7.

in the crop harvested. The differences are highly significant; the effect was very quickly found.

The high percentages found at 5½ months, when the canes were just starting to make millable stalk, were reduced sharply as additional millable cane was formed, and reached a low point when the crop was about a year old. A subsequent increase in these reducing sugars accompanied the increase in newer and younger stalks or sucker growth which then came into the population, and the reducing sugars continued to increase until the suckers were well grown out. Thereafter another reduction in per cent reducing sugars occurred. However, the amounts found at 20½ months for the 160- and 220-pound nitrogen treatments were still over 3 per cent and this indicates that the living stalks in the crop were still growing and not yet ready to be harvested.

(b) Per Cent Sucrose (Fig. 7) (Table 7 in Appendix): Significant differences in the percentage of sucrose were found between Treatments C and A (160 and 100 pounds N) at 8½, 9½ and 10½ months with the higher percentage found in Treatment A, and although not proved significant in later harvests there is a suggestion that A continued to have a higher concentration of sucrose than C. The

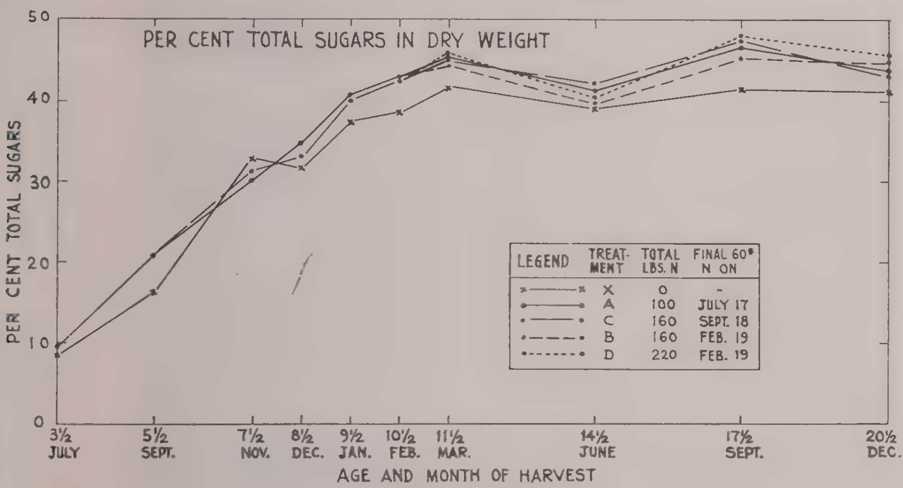

Fig. 8.

February applications of 60 pounds of nitrogen to make Treatments B (160 pounds) and D (220 pounds) had significantly reduced their per cent sucrose from Treatments A and C respectively by June, but this effect was less apparent in September and had almost entirely disappeared by December.

The general increase in per cent sucrose was very rapid during the first year of growth for all treatments, but there was very little change during the second year.

(c) Per Cent Total Sugars (Fig. 8) (Table 8 in Appendix): There is little evidence to indicate that the percentages of total sugars were influenced to any great extent by the different nitrogen treatments. The experimental errors for this measurement are not high, and yet no significant differences are to be found.

All treatments showed a rapid increase in their per cent total sugars between 3½ and 11½ months and reached a concentration between 44 and 46 per cent. Six months later this concentration had only been increased to between 46 and 48 per cent and during the subsequent 3 months there was a slight decrease from this maximum.

(d) Per Cent Nitrogen (Fig. 9) (Table 9 in Appendix): The effect from the different nitrogen applications was almost immediately identified in the percentages

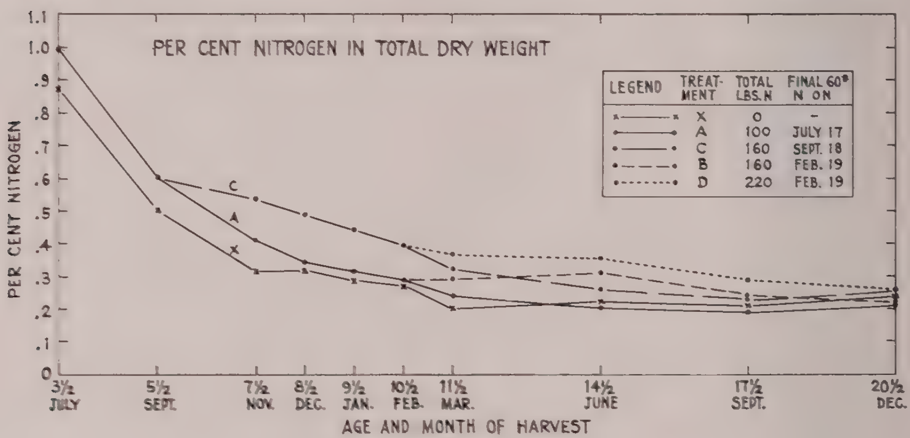

Fig. 9.

of nitrogen found in the dry weight. From a .993 per cent high point at 3½ months, the general decrease in concentration was quite rapid. At 10½ months the crop from the "C" plots which had already received 160 pounds of nitrogen had .396 per cent N in its total dry weight, whereas that from the A plots (100 pounds N) had only .293 per cent N. The subsequent application of nitrogen (60 pounds in February) for the B and D plots slowed up this decrease. There was only a little additional decrease during the second year, and at 20½ months all treatments had arrived at an amount between .211 and .254 per cent.

One of the figures we are interested in from this study is this percentage of nitrogen in the total dry weight at 10½ months. We still seek an index of a critical nitrogen concentration in the sugar cane crop. In this study at 10½ months we have two series of 16 plots each which have already received 100 and 160 pounds of nitrogen, and we have found the per cent N in samples of their total dry weight. From an additional application of 60 pounds of N given at 11 months to half (8) of the plots in each of these two series, we have measured the effects on the field yields of this crop which was finally harvested at 23 months. To study the relationships between the percentage of nitrogen in the crops at 10½ months and the final yields, and also for a comparison with the two previous harvests from this study, we have prepared the following summary (Table I):

TABLE I

RELATION BETWEEN PER CENT N IN DRY WEIGHT AT 10½ MONTHS AND THE FINAL FIELD YIELDS OF CANE AND SUGAR AT 23 MONTHS

Crop	No. of Plots	Plot Identity	At 10½ mos. Lbs. N Applied	At 10½ mos. % N in Dry wt.	Treatment	Additional N at 11 mos. (lbs.)	Field Harvest Final Yields TCA	Y%C	TSA
Plant	16	A+B	100	.34	A	0	111	13.9	14.7
					B	60	120	13.2	15.7
"	16	C+D	160	.43	C	0	120	13.1	15.6
					D	60	123	12.7	15.5
1st Ratoon	16	A+B	100	.29	A	0	115	11.1	12.7
					B	60	127	10.5	13.2
"	16	C+D	160	.37	C	0	126	10.9	12.6
					D	60	137	9.7	13.2
2nd Ratoon	16	A+B	100	.29	A	0	119	10.3	12.1
					B	60	128	9.9	12.5
"	16	C+D	160	.40	C	0	132	9.8	12.8
					D	60	135	9.1	12.3

In the plant crop the critical nitrogen level for total dry weight appeared to be above .34 but not above .43 per cent, whereas in the first ratoon it was believed to be above .37 per cent. In this second ratoon, although the final yield differences between treatments were not proved to be significant, there is a consistent trend of cane yield increases from the increased applications of nitrogen and, although these increases are probably also associated with poorer cane quality, the differences in sugar yields suggest perhaps that the critical N level is above .29 but not above .40 per cent. While these limits between the critical index of inadequacy and adequacy of per cent N in total dry weight of cane at 10½ months are admittedly fairly close together, the sampling and analytical errors need not be high, and this measurement should be useful for guidance in nitrogen fertilization. If our interpretation is correct, we would expect a gain in sugar from an additional 60 pounds application of nitrogen at 11 months if the per cent N in the total dry weight were only .3 per cent, but no gain if the per cent N at this time were .4 per cent.

(e) Per Cent Phosphoric Acid and Potash (Fig.10) (Tables 10 and 11 in Appendix): The omission of all nitrogen fertilizer has resulted in a higher concentration of both phosphoric acid and potash in the crop from the X plots. The higher applications of nitrogen have generally lowered the percentages of phosphoric acid and potash. Thus an inverse relationship between the nitrogen concentration and the concentration of phosphate and potash in the cane plant is again indicated.

The general decrease in the concentration of P_2O_5 and K_2O between 3½ and 11½ months and the leveling off thereafter is not unlike the change in per cent N. The per cent P_2O_5 at 3½ months was exceptionally high in spite of the fact that neither this crop nor the preceding one had been given any phosphate fertilizer. The potash concentration was in general slightly higher than was found in the first ratoon crop.

(f) Total Nutrition and Nutrition Ratios: Table II carries a summary of the nutrient composition of the total dry weight from each harvest. The effect of the nitrogen applications is seen in the increased percentages from each additional increment given. The corresponding but opposite effect on phosphate and potash is quite clear.

The index of total nutrition (the sum of the percentages of N, P_2O_5, and K_2O) is highest for Treatment X, yet yields from Treatment X were definitely lower than from other treatments which received nitrogen fertilizer.

The best cane quality at 20½ months (Y%C at 9.2) came from Treatment A which had a so-called "quality of nutrition" (the m.e. ratio of N-P_2O_5-K_2O) of 31-23-46. However, a very similar quality of nutrition (32-20-48) at 8½ months was associated with a Y%C of only 6.2 in Treatment X.

The best sugar yield (11.2 T.S.A.) came from Treatment B at 20½ months when this treatment had an index of total nutrition of 1.279 per cent and a quality

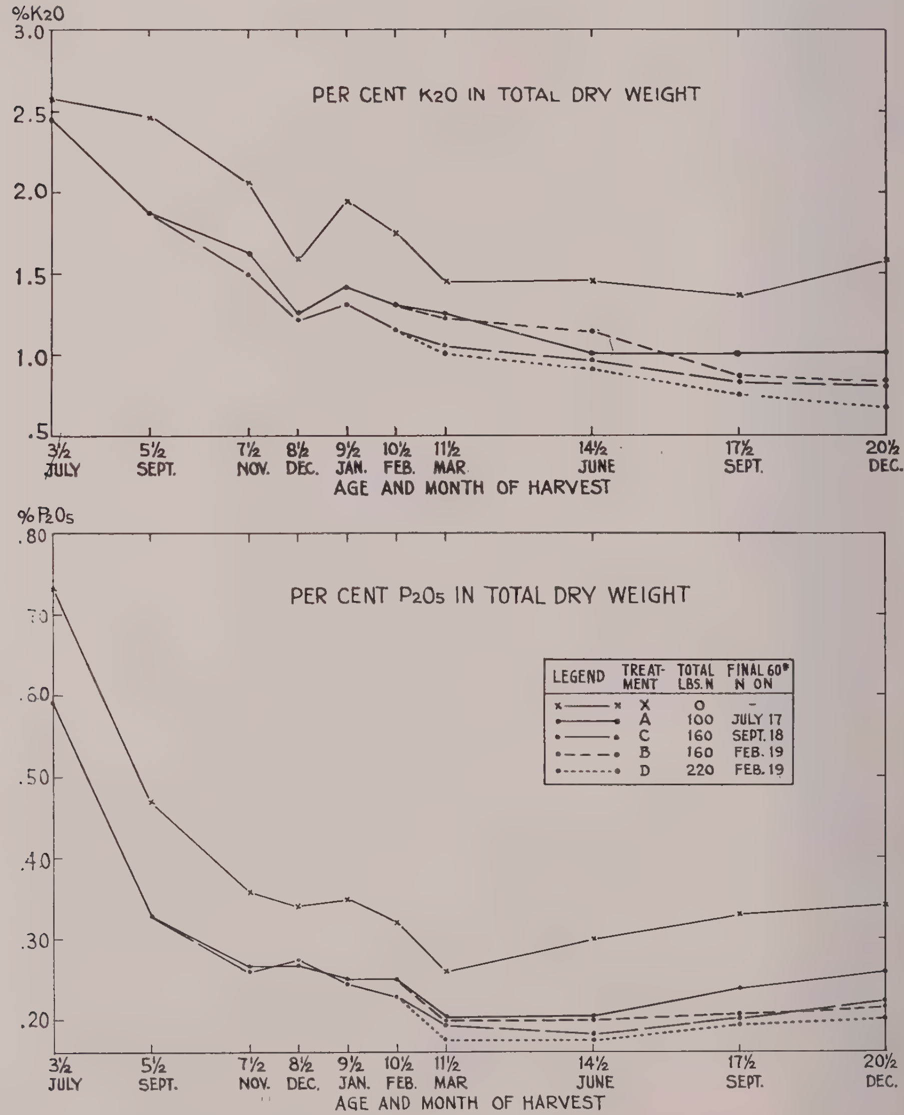

Fig. 10.

TABLE II

NUTRIENT COMPOSITION OF TOTAL DRY WEIGHTS

Treat-ment	Age (mos.)	Lbs. N to date	Percentages in total dry weight: N	P_2O_5	K_2O	Sum ($N+P_2O_5+K_2O$)	Ratio* N-P_2O_5-K_2O	$P_2O_5+K_2O \div N$	Pounds per acre in total dry weight: total lbs. N-P_2O_5-K_2O	proport. (%) N-P_2O_5-K_2O
X	3½	0	.868	.736	2.570	4.174	42-21-37	1.38	123	20-18-62
A	"	40	.993	.591	2.444	4.028	48-17-35	1.09	169	24-15-61
X	5½	0	.504	.471	2.468	3.443	33-18-49	2.01	344	15-13-72
A	"	100	.604	.330	1.866	2.800	45-14-41	1.25	466	21-12-67
X	7½	0	.322	.359	2.059	2.740	28-19-53	2.57	430	12-13-75
A	"	100	.408	.264	1.626	2.298	39-15-46	1.57	590	18-11-71
C	"	160	.542	.262	1.486	2.290	47-14-39	1.10	674	24-11-65
X	8½	0	.316	.341	1.593	2.250	32-20-48	2.14	434	14-15-71
A	"	100	.344	.272	1.251	1.867	39-18-43	1.55	563	18-15-67
C	"	160	.493	.278	1.208	1.979	49-16-35	1.07	552	25-14-61
X	9½	0	.292	.351	1.950	2.593	27-19-54	2.70	534	11-13-76
A	"	100	.320	.254	1.405	1.979	36-17-47	1.78	675	16-13-71
C	"	160	.436	.246	1.297	1.979	45-15-40	1.22	701	22-12-66
X	10½	0	.268	.320	1.748	2.336	28-19-53	2.65	407	11-14-75
A	"	100	.293	.254	1.304	1.851	35-18-47	1.84	698	16-14-70
C	"	160	.396	.230	1.161	1.787	45-16-39	1.22	675	22-13-65
X	11½	0	.201	.264	1.463	1.928	25-20-55	2.95	540	10-13-77
A	"	100	.240	.206	1.244	1.690	33-17-50	2.05	787	14-12-74
B	"	160	.293	.204	1.243	1.740	37-16-47	1.68	745	17-12-71
C	"	160	.325	.189	1.065	1.579	43-15-42	1.32	811	21-12-67
D	"	220	.369	.177	1.082	1.628	46-13-41	1.16	798	22-11-67
X	14½	0	.221	.300	1.474	1.995	26-21-53	2.79	633	11-15-74
A	"	100	.207	.204	1.040	1.451	32-19-49	2.08	926	15-14-71
B	"	160	.310	.200	1.156	1.666	40-15-45	1.49	814	19-12-69
C	"	160	.264	.179	.965	1.408	40-16-44	1.49	905	19-12-69
D	"	220	.362	.175	.915	1.452	49-14-37	1.04	976	25-12-63
X	17½	0	.212	.334	1.375	1.921	26-24-50	2.87	945	11-17-72
A	"	100	.192	.239	1.009	1.440	30-22-48	2.31	950	13-17-70
B	"	160	.236	.202	.873	1.311	38-20-42	1.61	907	18-15-67
C	"	160	.229	.205	.832	1.266	38-20-42	1.61	1019	18-16-66
D	"	220	.280	.187	.763	1.230	45-18-37	1.21	839	23-15-62
X	20½	0	.237	.341	1.591	2.169	26-22-52	2.86	954	11-15-74
A	"	100	.211	.256	1.045	1.512	31-23-46	2.20	895	14-17-69
B	"	160	.228	.218	.833	1.279	38-21-41	1.66	919	19-17-64
C	"	160	.252	.224	.814	1.290	40-21-39	1.49	801	19-17-64
D	"	220	.254	.200	.680	1.134	44-21-35	1.27	821	22-18-60

* Based on chemical equivalents.

of nutrition of 38-21-41. In the previous crop, Treatment D at 20½ months had an index of nutrition of 1.306, and a quality of nutrition of 38-23-39 but had produced 17.0 T.S.A. Hence we are still having difficulty in interpreting these nutrition ratios to secure the desired guidance for nitrogen fertilization of sugar cane crops.

8. On the Composition of Leaves and Crusher Juices:

(a) Per Cent Nitrogen in the Leaf-Punch Samples (Fig. 11) (Table 12 in Appendix): Once more we find this measurement of the percentage of nitrogen in the leaf-punch samples from the active cane leaf blades to be a highly reliable reflection of the different nitrogen treatments. Highly significant differences were found at each date of sampling and the effects were apparent within less than a month after fertilizer was supplied.

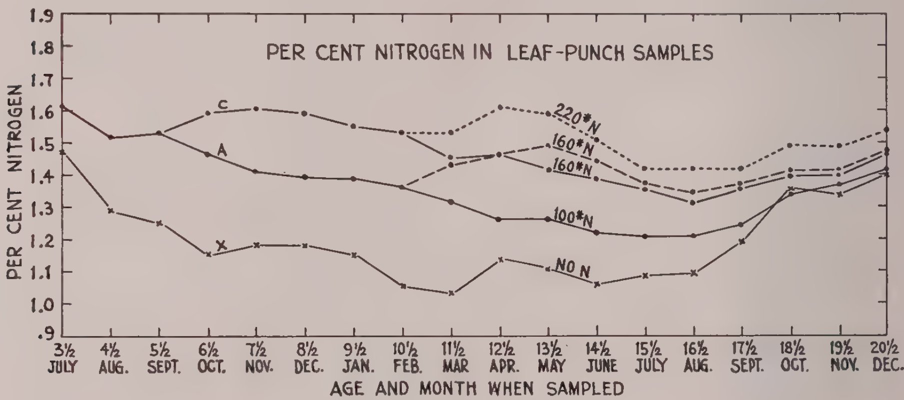

Fig. 11.

The nitrogen level in the leaf blades from this crop at 3½ months was only slightly higher than in the first ratoon, but considerably lower than in the plant crop at the same age. A normal decrease occurred during the first year until more nitrogen fertilizer was supplied, and then all treatments showed an increased percentage of N during the last 4 or 5 months before the December harvest. This fact can be tied in nicely with the relatively high level of available nitrogen that was found in the soil samples in May and June of the second year, and the evidence of a rapid depletion of this soil supply during the following months (see Fig. 1).

Our chief interest in this measurement centers in the amounts that were found in February when the crop was 10½ months old, for we seek a critical index from the active cane leaves at about this age of crop. So we have prepared Table III in order to record and compare the data from this crop with those from the two previous crops.

In this second ratoon we have assumed that a possibly better sugar yield came from Treatment B than from Treatment A. Apparently, then, 1.36 per cent N in the leaf-punch samples taken at 10½ months from Treatment A indicated a nitrogen inadequacy to carry the crop for another year, since the additional 60-pound application of nitrogen given to Treatment B at 11 months is assumed to have been effective. But there was certainly no increase in sugar for the extra nitrogen given

TABLE III

RELATION BETWEEN THE PERCENTAGES OF NITROGEN IN THE LEAF-PUNCH SAMPLES AT 10½ MONTHS AND THE FINAL YIELDS OF CANE AND SUGAR

Crop	No. of plots	Plot identity	At 10½ months lbs. N applied	At 10½ months % N in leaves	Treatment	Additional N at 11 mos. (lbs.)	Field harvest Final Yields T.C.A.	Field harvest Final Yields Y%C	Field harvest Final Yields T.S.A.
Plant	16	A+B	100	1.36	A	0	111	13.9	14.7
					B	60	120	13.2	15.7
"	16	C+D	160	1.46	C	0	120	13.1	15.6
					D	60	123	12.7	15.5
1st Ratoon	16	A+B	100	1.22	A	0	115	11.1	12.7
					B	60	127	10.5	13.2
"	16	C+D	160	1.38	C	0	126	10.9	12.6
					D	60	137	9.7	13.2
2nd Ratoon	16	A+B	100	1.36	A	0	119	10.3	12.1
					B	60	128	9.9	12.5
"	16	C+D	160	1.53	C	0	132	9.8	12.8
					D	60	135	9.1	12.3

to Treatment D over Treatment C, and so the 1.53 per cent N in "C" at 10½ months was apparently a sufficiently high level to maintain a subsequent year's production of sugar in this crop. This places the critical level for leaf-punch nitrogen in this second ratoon crop at 10½ months at somewhere between 1.36 and 1.53 per cent, and so comes very close to verifying the results from the plant crop when we believed the critical level to be between 1.36 and 1.46 per cent, and also from the first ratoon when the deficiency level appeared to be 1.38 per cent. Hence if these coincidental results are what we think they are, we have come a little closer to identifying a critical nitrogen index in the leaf blades of this cane variety.

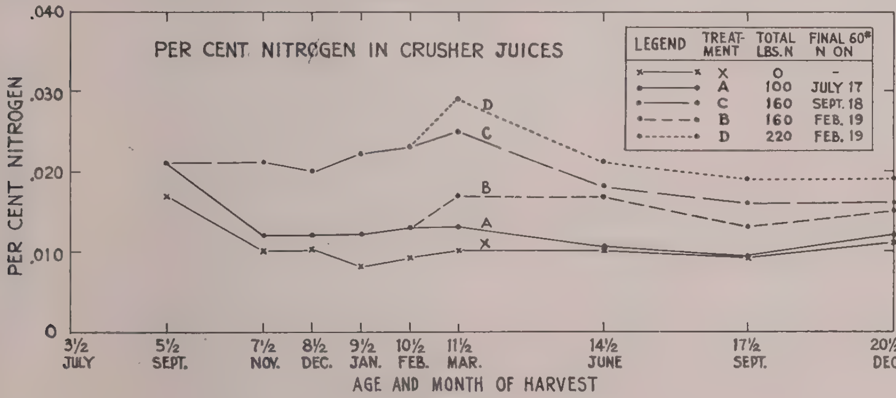

Fig. 12.

(b) Per Cent Nitrogen in the Crusher Juices (Fig. 12) (Table 13 in Appendix): This measurement has also been found to reflect the different nitrogen levels at which the crop was being grown, and even though the experimental errors are high, it has been possible to show some highly significant differences between the nitrogen treatments.

The interpretation of a critical point for per cent N in juice also hinges upon our willingness to assume that Treatment B possibly outyielded A in the yield of

sugar at the final field harvest, and that Treatment D was not better than Treatment C. With this assumption, it appears that the value of .013 per cent N at 10½ months was an index of inadequacy of nitrogen for another year's growth, whereas a value of .023 per cent was apparently quite adequate for this second ratoon crop.

From the three crops harvested, we have reported that .018 per cent, .020 and possibly even .033 per cent, and .013 per cent have been found to be too low for the percentage of nitrogen in the juice at 10½ months, and that .030 per cent and .023 per cent have indicated an adequate concentration at this age. Apparently this specific index has not yet been established with sufficient confidence to use it as a guide for the need of additional nitrogen applications.

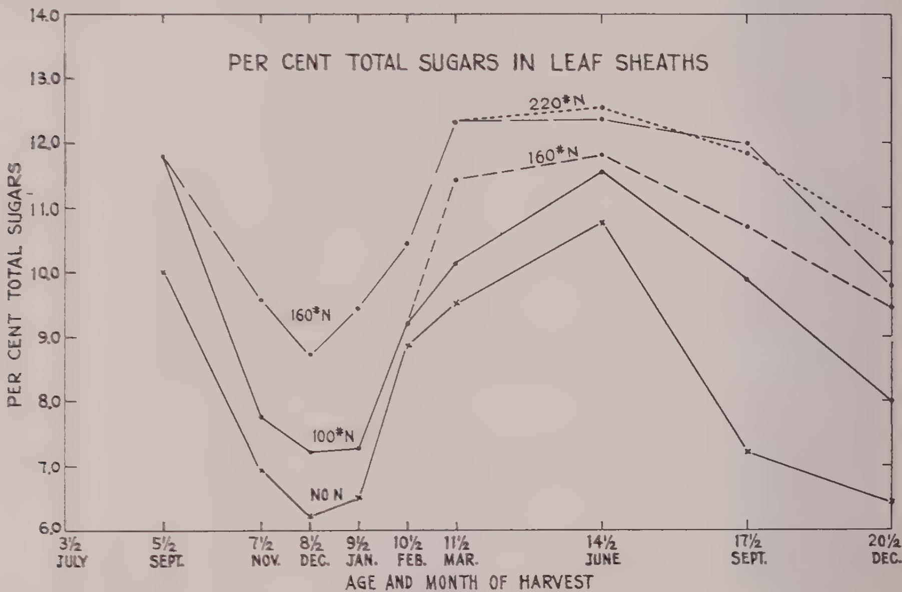

Fig. 13.

(c) Per Cent Total Sugars in Leaf Sheaths (Fig. 13) (Table 14 in Appendix): The Clements' system of crop control which is primarily concerned with the per cent of total sugars found in specific leaf sheaths at periodic harvests was given further study in this second ratoon crop. The premise that the per cent total sugars in leaf sheaths (the so-called primary index) indicates whether cane growth or sugar storage is prevailing in the crop under study is not supported by our data. At the age of 5½ months while the crop was making very rapid growth, the per cent total sugars in the leaf-sheath samples from the plots which had received 100 pounds of nitrogen and made over 8 tons of dry weight per acre was definitely higher at 11.80 per cent than that (10.03 per cent) from 5 tons of dry weight produced without nitrogen from Treatment X. Moreover this same relationship was found in subsequent samples, i.e.—a higher per cent total sugars and generally a larger amount of cane were produced when the nitrogen applications had been increased. These data together with the associated moisture (per cent moisture in leaf sheaths) and the nitrogen indices (per cent N in leaf-punch samples from leaf blades) are summarized in Table IV.

TABLE IV

THE PRIMARY, MOISTURE AND NITROGEN INDICES, AND THE TOTAL DRY WEIGHT HARVESTED AT 5½ TO 11½ MONTHS

Treatments	Lbs. N applied	Age	Primary index (1)	Moisture index (2)	Nitrogen index (3)	Total dry wt. tons/acre
X	0	5½ mos.	10.03	80.6	1.25	4.96
A, B, C & D	100	"	11.80	80.9	1.53	8.38
X	0	7½ mos.	6.97	80.6	1.18	7.89
A+B	100	"	7.73	81.0	1.41	12.99
C+D	160	"	9.62	83.2	1.61	14.82
X	0	8½ mos.	6.23	80.2	1.18	9.74
A+B	100	"	7.20	80.7	1.39	14.89
C+D	160	"	8.70	82.9	1.59	14.01
X	0	9½ mos.	6.50	79.9	1.15	10.20
A+B	100	"	7.26	81.2	1.38	17.19
C+D	160	"	9.40	82.6	1.55	18.09
X	0	10½ mos.	8.87	77.9	1.05	8.65
A+B	100	"	9.14	80.8	1.36	19.44
C+D	160	"	10.40	81.8	1.53	18.89
X	0	11½ mos.	9.50	77.4	1.03	14.03
A	100	"	10.13	79.5	1.32	23.35
B	160	"	10.47	79.9	1.43	22.25
C	160	"	12.34	80.2	1.45	25.64
D	220	"	12.33	80.4	1.53	24.56

(1) % Total sugars in leaf sheaths.
(2) % Moisture in leaf sheaths.
(3) % N in leaf-punch samples from blades.

The wide range in variation for the per cent total sugars in the leaf sheaths of 5-stalk stamples from adjacent plots is shown in Fig. 14. At the age of 5½ months in September all 32 plots had received an identical amount of nitrogen (100 pounds per acre), yet the standard deviation of 1.57 per cent for these 32 samples indicates that any *single* sample might be expected by chance alone to have a per cent total sugar in leaf-sheath figure anywhere between 8.65 and 14.94.

In subsequent samplings this same wide range in variation for per cent total sugars in leaf sheaths continued to exist between the replicated plots, e.g., within the 16 replicates of the C and D plots at 10½ months, this expected range would be from 8.83 to 13.09, within the 16 A and B plots it could be from 7.55 to 11.27. Thus the inadequacy of the single 5-stalk sample for this measurement is clearly seen.

(d) Per Cent Moisture in Leaf Sheaths (Fig. 15) (Table 15 in Appendix): The highest percentage of moisture that was found in the leaf-sheath samples was 83.2 per cent and came from Treatment C at 7½ months; this cane had received a thorough irrigation only 5 days earlier. At 10½ months in February, and 8 days after an irrigation, only 81.8 per cent moisture was found in the leaf sheaths of Treatment C, and at 14½ months in June, only 4 days after irrigating, this figure had decreased to 79.1 per cent.

Apparently the percentages of moisture as found in the leaf sheaths of a well-grown crop are affected more by the nitrogen supply than by the application of

PER CENT TOTAL SUGARS IN SAMPLES TAKEN AT 5½ MONTHS FROM 32 ADJOINING PLOTS WHICH HAD RECEIVED AN IDENTICAL AMOUNT (100 POUNDS) OF NITROGEN PER ACRE

	9 14.28	16 13.50	22 13.66	27 10.59			
4 11.11	8 12.52	15 13.16	21 11.92				
3 9.86	7 11.90	14 12.93	20 12.23	25 11.83	30 9.82	35 11.26	38 9.95
2 10.23	6 13.13	13 13.03	19 13.67	24 11.23	29 12.40	34 13.41	37 8.06
1 11.26	5 11.20	12 10.83	18 10.83	23 8.64	28 13.94	33 14.06	36 11.02

Fig. 14.

irrigation water, for each time nitrogen fertilizer was supplied there was a corresponding increase or at least a retardation of decrease in the moisture content. The relative positions of the five nitrogen treatments, with respect to per cent moisture in sheaths, are very similar to those which we found for per cent moisture in total green weight (Compare Fig. 15 with Fig. 4); i.e., there was a higher percentage of moisture in the sheaths of the cane which had access to the greater supplies of nitrogen, and this relationship held regardless of differences which must have occurred from time to time in the soil moisture supplies.

9. On the Yields per Acre:

High experimental errors found in measurements when cane samples are small make it difficult to identify significant treatment effects on yields. Averages, however, have been recorded from 3 X plots at all harvests, from 32 similarly fertilized plots at 3½ and 5½ months, from 16 (A and B) plots and 16 (C and D) at 7½, 8½, 9½, and 10½ months, and from 8 replicates of each of these last four treatments at the last four harvests. All yields (excluding those for Treatment X) have been studied by analysis of variance.

(a) Reducing Sugars, Sucrose, and Total Sugars (Tables 16, 17 and 18 in Appendix): In spite of the high errors associated with the yields of reducing

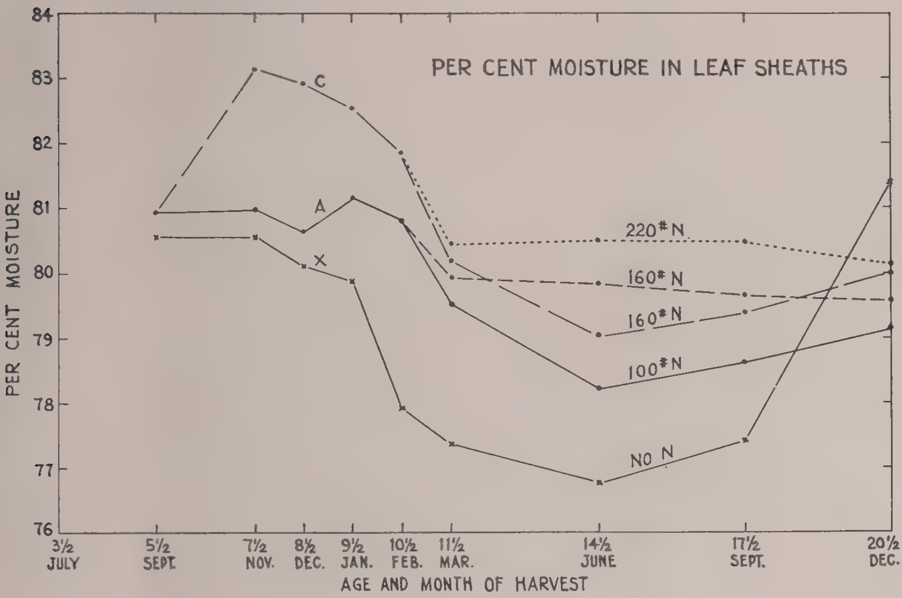

Fig. 15.

sugars, there are some highly significant differences between the treatments, and it is quite apparent that the increased nitrogen applications have increased the actual amounts of reducing sugars that were harvested.

The treatment effects on sucrose and total sugars are not as nicely proved.

TABLE V

SUGARS IN TOTAL DRY WEIGHT—TONS PER ACRE

Treatment	Total lbs. N applied by Feb.	Last 60 lbs. N applied	March harvest at 11½ mos. —Tons per acre— Red. sugar	Sucrose	Tot. sugars	June harvest at 14½ mos. —Tons per acre— Red. sugar	Sucrose	Tot. sugars
A	100	July	.52	9.72	10.75	.69	11.85	13.16
B	160	Feb.	.44	9.18	10.08	1.00	8.32	9.75
C	160	Sept.	.83	10.38	11.69	.97	11.89	13.48
D	220	Feb.	.80	9.98	11.31	1.69	11.09	13.38

Treatment	Sept. harvest at 17½ mos. —Tons per acre— Red. sugar	Sucrose	Tot. sugars	Dec. harvest at 20½ mos. —Tons per acre— Red. sugar	Sucrose	Tot. sugars
A	.83	13.81	15.36	.69	11.88	13.19
B	1.71	13.34	15.75	1.32	14.03	16.09
C	1.75	16.41	19.04	.96	11.71	13.30
D	2.25	13.30	16.26	1.68	14.15	16.57

In Table V we have summarized these yields from the last four harvests, and we note some possible changes in the N effects at the later harvests from those of the earlier harvests. Thus, Treatment B which may have produced slightly less sucrose than Treatment A at 11½, 14½ and 17½ months appears to have produced more than A at 20½ months; the same situation exists between Treatments D and C. In yields of total sugars, B was below A at 11½ and 14½ months but apparently exceeded A at later harvests; similarly Treatment D has probably produced more total sugars than C at the final harvest but not at the earlier harvests. Apparently

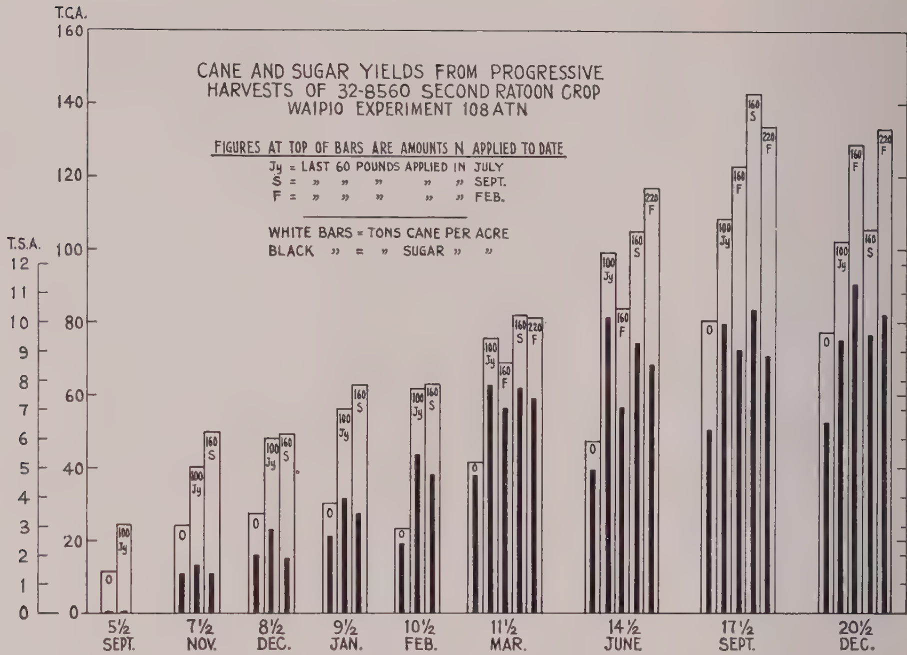

Fig. 16.

there is a time factor concerned with the effects on yields of sucrose and total sugars which come from increased nitrogen applications.

(b) Millable Cane and Recoverable Sugar (Fig. 16) (Tables 19 and 20 in Appendix): Preharvest yields from all sample rows have been calculated on their net area (25 square feet per plot), and are higher than reported for final field yields which were calculated from the gross area of the field plots.

By the time the crop was 10½ months old it had made more than 60 tons of cane and 5 tons of sugar per acre, with probably a little more sugar from the 100 pounds of N than from the 160 pounds which it had received. At 11½ months (March) the cane quality had improved to such an extent that together with the increased cane yields, there was estimated to be about 7.5 tons of recoverable sugar in the field, but no larger amount from the 160 than from the 100 pounds of nitrogen which had been supplied earlier.

"100-ton" cane had been produced in 14½ months by Treatment C, and the yield from Treatment A was not much below C. However, the extra 60-pound application of N which C had received over A, some 9 months previously, was having its depressing effect on cane quality, and the recoverable sugar from A was still the higher. In fact at 14½ months, Treatment A which had received only 100 pounds of nitrogen had produced the maximum amount of sugar per acre per month that we recorded from these second ratoon harvests, and nothing further was gained by harvesting this Treatment A at a more advanced age.

At 17½ months, Treatment C (160 pounds N, early) had produced more cane and also more recoverable sugar than A, but its rate of production was still below

that of .70 ton-sugar-per-acre-per-month which had been recorded for A at 14½ months.

The last preharvest samples taken at 20½ months show Treatment B (160 pounds N, late) in the lead. This is due to a great improvement in its cane quality, and to a sharply decreased cane yield from Treatment C.

The effects from the February applications of nitrogen to Treatments B and D at 11 months are not too clear. They can perhaps be studied best from Table VI. In the fourth growth period (at 11½-14½ months) the extra 60 pounds of nitrogen given to Treatment B did not increase its cane or sugar yield over Treatment A (100 pounds), whereas the extra 60 pounds given to Treatment D apparently did increase the cane yield over Treatment C (160 pounds).

TABLE VI

AVERAGE INCREASES OR DECREASES IN YIELDS OF T.C.A. and T.S.A.

Growth Period	No. of Months	Months	Age of crop (mos.)	T.C.A. (net area) X	A	B	C	D	True avg. for 5 treatments
1	5½	Apr.-Sept.	0 - 5½	+11.7	+22.0	+27.2	+21.1	+26.6	+23.1
2	3	Sept.-Dec.	5½- 8½	+16.1	+30.0	+16.8	+28.0	+23.4	+23.8
3	3	Dec.-March	8½-11½	+13.6	+23.3	+24.8	+32.6	+31.1	+26.8
4	3	Mar.-June	11½-14½	+ 5.6	+23.5	+14.7	+23.3	+35.5	+22.6
5	3	June-Sept.	14½-17½	+33.4	+10.1	+40.0	+38.4	+17.1	+27.0
6	3	Sept.-Dec.	17½-20½	— 3.5	— 6.6	+ 5.3	—38.2	— 1.5	— 9.7

Growth Period	T.S.A. (net area) X	A	B	C	D	All 5 treatments
1	+ .02	0	0	+ .02	+ .10	+ .03
2	+1.8	+2.9	+2.9	+1.9	+1.8	+2.3
3	+2.7	+4.9	+4.1	+5.8	+5.5	+4.9
4	+0.1	+2.3	0	+1.5	+1.1	+1.1
5	+1.4	—0.2	+2.0	+1.2	+0.3	+0.9
6	+0.3	—0.6	+2.2	—1.4	+0.9	+0.3

TABLE VII

TONS OF SUGAR PER ACRE PER MONTH

Treatment	Total lbs. N applied by Feb.	Last 60 lbs. N applied	T.S.A.M March at 11½ mos.	June at 14½ mos.	September at 17½ mos.	December at 20½ mos.
A	100	July	.68	.70	.57	.45
B	160	Feb.	.61	.48	.51	.55
C	160	Sept.	.67	.63	.59	.44
D	220	Feb.	.64	.59	.50	.47

From 14½ to 17½ months, B made a tremendous gain in cane over A, whereas D made perhaps only half as much more cane as C, and while B made much more sugar than A, Treatment D was making much less than C. If we combine these two periods (11½ to 17½ months), then during these six months we find (a) that B has produced 21 tons of cane more than A from its extra 60 pounds of nitrogen over A, whereas D has not made as much as C, and (b) although no increase in sugar has resulted from the extra nitrogen given to B, D with its extra N apparently produced even less sugar than C.

After 17½ months, the picture changed again. Treatment B made a slight gain in cane while A experienced a loss. On the other hand, while D apparently held its own, C showed a loss in cane that was just about equal to the gain which it had made in the previous growth period. Similarly while B made a respectable gain in

sugar. A lost a little; and while D was making a small gain C was losing some of the sugar which it has previously made.

Sugar-per-acre-per-month values (Table VII) were quite satisfactory at 11½ months, and also at 14½ months for Treatments A and C but these values dropped quite fast as the crop age was increased. Treatment A (100 pounds N) made the best showing at 14½ months.

9. Relation Between Recoverable Sugar and Total Sucrose (Table VIII): The effects of the different nitrogen treatments on the ratio of recoverable sugar to total sucrose were quite consistent; the nitrogen additions usually lowered this ratio, especially during the earlier growth periods. The drop in this ratio at 17½ months was common to all treatments. It too is probably an effect from an increased supply of available nitrogen which we believe made itself apparent in the "greening up" of the leaves of the X or no-nitrogen plots and their increased number of stalks, and with generally higher green weights, concentrations of reducing sugars, and higher percentages of nitrogen in the leaves of all of the treatments.

TABLE VIII

RATIO OF T.S.A. TO TOTAL TONS SUCROSE

	At 5½ mos.	7½	8½	9½	10½	11½	14½	17½	20½
X	.04	.60	.73	.76	.77	.84	.86	.68	.80
A	.03	.52	.67	.65	.72	.80	.85	.72	.78
B	..	..	..	..	..	.76	.84	.67	.80
C	..	.38	.54	.57	.69	.74	.77	.63	.77
D	..	..	..	..	..	.74	.77	.66	.69

10. On Cane Quality (Fig. 17) (Table 21 in Appendix):

Cane quality, measured as yield per cent cane, has again been adversely influenced by increased applications of nitrogen. Apparently the best quality was reached at 11½ months in March before the suckers contributed much to the crop and before the primary stalk mortality was a serious factor.

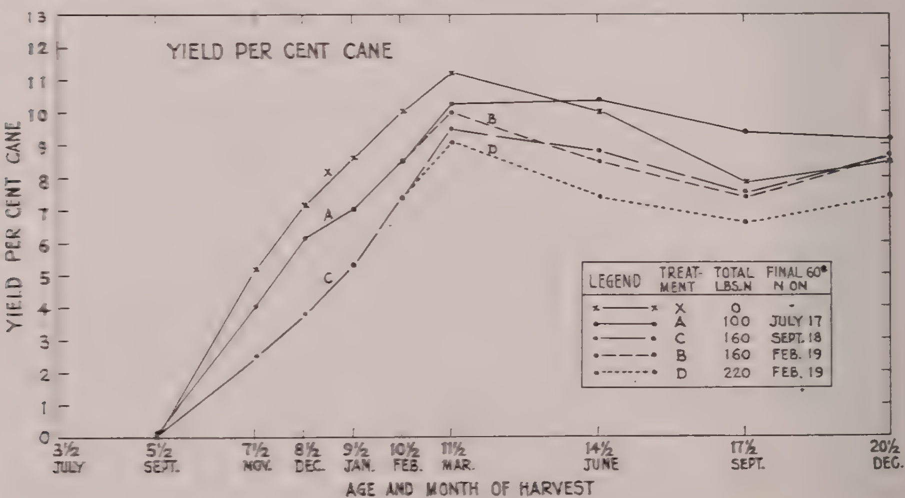

Fig. 17.

The withholding of the last 60 pounds of nitrogen until 11 months for Treatment B did not result in a poorer quality of cane than its earlier application at 6 months on Treatment C.

11. On Tonnage of Cane Tops:

The tonnage of cane tops gives a pretty fair idea of the amount of green-leaf surface that is active in photosynthesis. Our nitrogen applications have had a direct effect on the cane tops, especially during the early periods of growth.

The highest average amount of cane tops was reached in November at the age of 7½ months. For several months thereafter there was a steady decline. The next highest amount was reached in June at 14½ months and this also was followed by a general decrease. (Note, however, the increased amount of cane tops from Treatment X at 17½ months.)

TONS CANE TOPS PER ACRE

Lbs. N applied	5½ mos.	7½ mos.	9½ mos.
X- 0	12.1	10.0	11.6
A-100	18.2	19.0	17.2
C-160	....	22.2	18.3

Lbs. N applied	14½ mos.	17½ mos.	20½ mos.
X 0	10.1	15.4	13.4
A 100	16.5	15.5	12.8
B 160	18.0	19.4	15.8
C 160	18.4	17.5	15.7
D 220	23.3	18.0	15.5

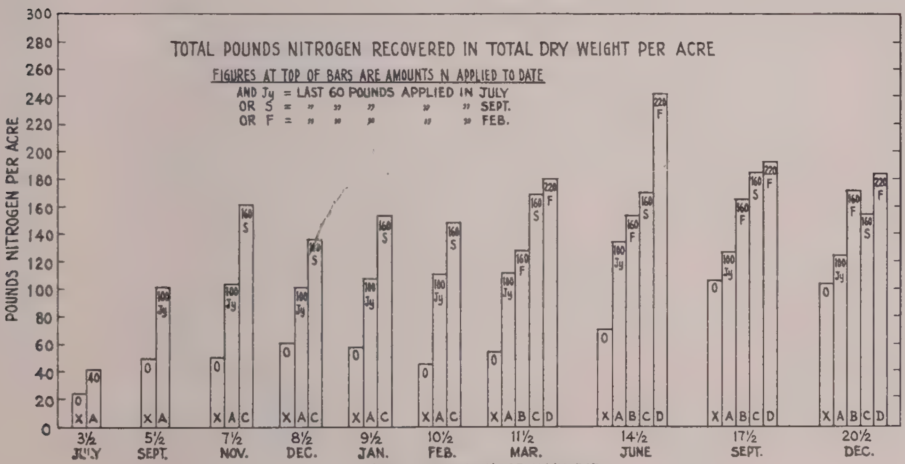

Fig. 18.

12. On the Recovery of Nutrients in the Total Dry Weight:*

(a) Nitrogen (Fig. 18) (Table 22 in Appendix): The cane crop harvested from the X plots carried between 50 and 60 pounds of nitrogen which it took from the unfertilized soil during its first year's growth; it then went on to take up double this amount from the soil supply between 11½ and 17½ months.

At 5½ months the A crop carried only about 100 pounds of nitrogen per acre, and the total nitrogen in this crop didn't increase much above 100 pounds during the rest of the first year, i.e., only a small amount was picked up thereafter. Similarly, within two months after Treatment C had received its total of 160

* Except trash and roots.

pounds of N, its crop was carrying an equivalent amount, and its additional increase during the second year was quite small too. While we recognize that these second-year recoveries are incomplete because of the nitrogen in the trash that has been unaccounted for, the evidence of a very rapid uptake of nitrogen at about 5 to 6 months of age is real and of considerable importance. From the 60 pounds of N supplied for Treatment C in September there is an average recovery from the subsequent eight harvests of 44 pounds more nitrogen from C than from A. From the 60-pound applications made in February to Treatments B and D there is an average recovery in the four subsequent harvests of only 30 pounds more N than from Treatments A and C.

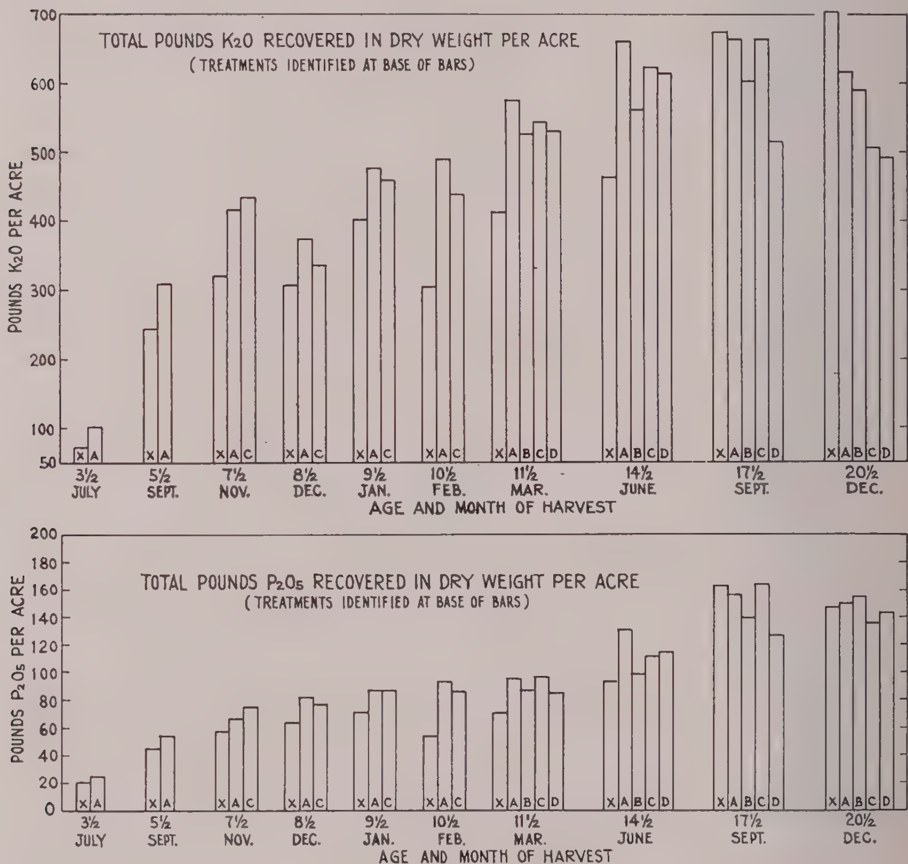

Fig. 19.

(b) Phosphoric Acid and Potash (Fig. 19) (Tables 23 and 24 in Appendix): There were no significant effects from the different nitrogen treatments upon the total pounds of P_2O_5 or of K_2O that were found in the crops that were harvested. We have previously noted (Fig. 10) and commented that the percentages of these two nutrients appeared to be decreased as the nitrogen totals were increased. But since the increased nitrogen also increased the total dry weight, the decreased P_2O_5

and K_2O concentration could be an effect of dry-matter dilution and not necessarily a nitrogen effect.

A study of the P_2O_5 data in Fig. 19 shows that in eight comparisons of Treatments A and C, four cases show A with the higher amount of P_2O_5, two favor C, and two are even. For the four comparisons of Treatments A and B, three favor A and one favors B, and for the four C and D comparisons, two favor C and two D. These results are not sufficiently consistent to indicate that there have been any nitrogen treatment effects upon the total amount of phosphate found in the crops which we have harvested.

From the K_2O data, we note that Treatment A has more potash than C in six out of eight comparisons, that A has more than B in all four comparisons, and that C has more than D in all four comparisons. This is a much better indication that the higher nitrogen application may have resulted in the uptake of less potash by the crops harvested.

Weather Relationships

The basic weather data during the development of this second ratoon crop are given in Table IX; they have been summarized for six periods of growth. These weather data have been studied in connection with the yields from Treatments B and C which in the final field harvest gave the highest sugar yields. The sunlight and temperature utilization by these two treatments is summarized in Table X.

Interpretation of these data is again very difficult. One thousand gram calories had its greatest effect on all five measurements from Treatment C between December and March when the crop was 8½ to 11½ months old. This was also true for Treatment B in the case of total sugars and commercial sugar, but for green and dry weights and for millable cane, the gram calories were more effective from June to September when the cane was 14½ to 17½ months old.

One thousand day-degrees had many effects similar to gram calories. They were most effective on all yields from Treatment C at 8½ to 11½ months, and on dry weights and sugars from Treatment B in this same growth period, but for

TABLE IX
BASIC WEATHER DATA

Growth period	Dates	Crop age mos.	Gram calories	Hours sun	Day-deg.	Avg. temp. min.	Avg. temp. max.	Avg. range in temperat.	Avg. wind velocity (m.p.h)
1	3/25- 9/10	0 - 5½	98,429	1489	2335	67.5	84.2	16.7	7.7
2	9/11-12/10	5½- 8½	40,124	696	1301	65.9	84.5	18.6	6.0
3	12/11- 3/18	8½-11½	39,702	712	1167	61.9	82.0	20.1	5.4
4	3/19- 6/11	11½-14½	43,441	679	1391	64.9	86.6	21.7	5.2
5	6/12- 9/13	14½-17½	49,817	723	1661	67.6	90.0	22.4	4.9
6	9/14-12/11	17½-20½	41,213	729	1707	67.1	87.4	20.3	4.6

Increase in Yields (tons/acre)
Treatments B and C

Growth period	Green. wt. B	Green. wt. C	Dry wt. B	Dry wt. C	T.C.A. B	T.C.A. C	Tot. sugars B	Tot. sugars C	T.S.A. B	T.S.A. C
1	42.1	42.1	8.38	8.38	24.2	24.2	1.78	1.78	.03	.03
2	22.8	25.4	6.51	5.63	23.8	25.4	3.41	2.91	2.87	1.87
3	19.2	33.0	7.36	11.63	20.8	32.1	4.89	7.00	4.10	5.80
4	17.5	22.3	2.36	6.36	14.7	23.3	–.33	1.79	0	1.50
5	40.8	37.9	9.99	8.00	40.0	38.4	6.00	5.56	2.00	1.20
6	2.1	–40.0	1.62	–9.33	5.3	–38.2	.34	–5.74	2.20	–1.40

TABLE X

SUNLIGHT AND TEMPERATURE UTILIZATION BY TREATMENTS B AND C

Growth period	Tons total green weight per acre					
	Per 1000 gram calories		Per 100 hrs. of sunshine		Per 1000 day—degrees	
	B	C	B	C	B	C
1	.428	.428	2.827	2.827	18.030	18.030
2	.568	.633	3.276	3.649	17.525	19.523
3	.484	**.831**	2.697	4.635	16.452	**28.278**
4	.403	.513	2.577	3.284	12.581	16.032
5	**.819**	.761	**5.643**	**5.242**	**24.564**	22.818
6	.051	(loss)	0.288	(loss)	1.230	(loss)

Growth period	Tons total dry weight per acre					
	Per 1000 gram calories		Per 100 hrs. of sunshine		Per 1000 day—degrees	
	B	C	B	C	B	C
1	.085	.085	.563	.563	3.589	3.589
2	.162	.140	.935	.809	5.004	4.327
3	.185	**.293**	1.034	**1.633**	**6.307**	**9.966**
4	.054	.146	.348	.937	1.697	4.572
5	**.201**	.161	**1.382**	1.107	6.014	4.816
6	.039	(loss)	.222	(loss)	.949	(loss)

Growth period	Tons millable cane per acre					
	Per 1000 gram calories		Per 100 hrs. of sunshine		Per 1000 day—degrees	
	B	C	B	C	B	C
1	.246	.246	1.625	1.625	10.364	10.364
2	.593	.633	3.420	3.649	18.294	19.523
3	.524	**.809**	2.921	4.508	17.823	**27.506**
4	.338	.536	2.165	3.432	10.568	16.751
5	**.803**	.771	**5.533**	**5.311**	**24.082**	23.119
6	.129	(loss)	.727	(loss)	3.105	(loss)

Growth period	Tons total sugars per acre					
	Per 1000 gram calories		Per 100 hrs. of sunshine		Per 1000 day—degrees	
	B	C	B	C	B	C
1	.018	.018	.120	.120	.762	.762
2	.085	.073	.490	.418	2.621	2.237
3	**.123**	**.176**	.687	**.983**	**4.190**	**5.998**
4	(loss)	.041	(loss)	.264	(loss)	1.287
5	.120	.112	**.830**	.769	3.612	3.347
6	.008	(loss)	.047	(loss)	.199	(loss)

Growth period	Tons commercial sugar per acre					
	Per 1000 gram calories		Per 100 hrs. of sunshine		Per 1000 day—degrees	
	B	C	B	C	B	C
1	.0003	.0003	.002	.002	.013	.013
2	.072	.047	.412	.269	2.206	1.437
3	**.103**	**.146**	**.576**	**.815**	**3.513**	**4.970**
4	0	.035	0	.221	0	1.078
5	.040	.024	.277	.166	1.204	.722
6	.053	(loss)	.302	(loss)	1.289	(loss)

green weight and millable cane yield from B, the day-degrees were most effective at 14½ to 17½ months.

One hundred sunshine hours were most effective on total green weight and millable cane from both treatments B and C during the 14½ to 17½ months growth period. On total dry weight and total sugars, the greatest effectiveness from sunlight hours occurred at 8½ to 11½ months for Treatment C, but at 14½ to 17½ months for Treatment B. For commercial sugar production, both B and C received greatest benefits from 100 sunshine hours when they were 8½ to 11½ months old,—December to March. All together these data again show the very different effect on yields at different crop-age periods which different weather factors can have.

Other Interesting Relationships

1. Ratio of Per Cent Total Sugars to Per Cent N in Total Dry Weight:

At the age of 5½ months in September the crop which had already received 100 pounds of nitrogen showed a concentration of total sugars that was 35 times its concentration of nitrogen. In subsequent harvests this increased until at 10½ months it reached a concentration 146 times that of nitrogen. The corresponding ratios of total sugars to nitrogen in the crops which had received 160 pounds of nitrogen were somewhat below those of the crops which received 100 pounds, and at 10½ months this ratio was 107 to 1. With the assumption that the final yields have indicated (but not proved) that 100 pounds of N were inadequate, it would appear that the ratio of 146 to 1 was too wide and hence an index of an undesirably high carbohydrate-nitrogen status at 10½ months, which called for an additional nitrogen application.

RATIO OF PER CENT TOTAL SUGARS TO PER CENT N IN TOTAL DRY WEIGHT

Treatment	No. of plots	Lbs. N applied	Harvested in— November 7½ mos.	December 8½ mos.	January 9½ mos.	February 10½ mos.
A+B	16	100	73.8	100.6	126.1	146.2
C+D	16	160	57.7	67.2	92.0	106.7

2. Ratio of Pounds of Nitrogen Per Acre Recovered in Crop to Tons Millable Cane Harvested:

Excluding the amount of nitrogen which has been left unaccounted for in the roots and dry trash, we have recovered from this crop an amount of nitrogen per ton of cane that is quite similar to that found previously; this amount is probably not over 1.5 pounds per ton of cane.

POUNDS N PER TON OF CANE

Treatment	At 14½ mos.	At 17½ mos.	At 20½ mos.	In previous crops at 20½ mos— plant	1st ratoon
X	1.5	1.3	1.3	1.1	1.2
A	1.4	1.2	1.2	1.2	1.2
B	1.8	1.3	1.3	1.4	1.3
C	1.6	1.3	1.5	1.4	1.2
D	2.1	1.4	1.4	1.7	1.5

3. Ratio of Per Cent Reducing Sugars to Per Cent Sucrose:

Each added amount of nitrogen has resulted in a consistent increase in this ratio of reducing sugars to sucrose. These increases became smaller as the harvesting

period was advanced farther away from the date when the nitrogen applications were made.

RATIO OF PER CENT REDUCING SUGARS TO PER CENT SUCROSE

Treatment	Harvested in— July	Sept.	Nov.	Dec.	Jan.	Feb.	Mar.	June	Sept.	Dec.
X	1.03	.60	.15	.07	.06	.03	.03	.05	.07	.05
A	1.14	.80	.23	.15	.11	.08	.05	.05	.06	.06
B	....	...	...	...	...	...	.05	.12	.12	.09
C	....	...	.33	.29	.19	.12	.08	.08	.10	.08
D	....	...	...	...	...	...	.08	.15	.16	.12

4. Ratio of Total Sugars to Total Dry Weight (Tons per Acre):

There has been very little effect on the ratios of total sugars to total dry weight that can be attributed to the different nitrogen treatments. After November when we have a comparison between canes that have received 100 and 160 pounds of nitrogen (A vs. C), we find almost identical ratios, and this is also true for the harvests which came after March when further differences in nitrogen treatments had shown positive effects on some of the other ratios. Hence, regardless of the nitrogen treatments this 32-8560 ratoon crop has made a yield of total sugars at 20½ months which was about 44 per cent of its total dry weight.

RATIO OF TOTAL SUGARS TO TOTAL DRY WEIGHT (TONS/ACRE)

Treatment	Harvested in— July	Sept.	Nov.	Dec.	Jan.	Feb.	Mar.	June	Sept.	Dec.
X	.08	.17	.32	.32	.37	.39	.43	.39	.41	.41
A	.10	.21	.31	.35	.41	.43	.46	.41	.47	.44
B	...	...	...	...	...	...	.45	.40	.46	.44
C	...	...	.31	.33	.41	.42	.46	.42	.48	.43
D	...	...	...	...	...	...	.46	.40	.47	.45

5. Ratio of Tons Reducing Sugars to Total Dry Weight:

All harvests show an increased ratio of the yields of reducing sugars to total dry weights which are the direct effects from the increased nitrogen applications.

RATIO OF TONS REDUCING SUGARS TO TOTAL DRY WEIGHT

Treatment	Harvested in— July	Sept.	Nov.	Dec.	Jan.	Feb.	Mar.	June	Sept.	Dec.
X	.041	.060	.039	.022	.020	.012	.009	.018	.027	.020
A	.052	.089	.055	.043	.040	.028	.022	.022	.025	.023
B	....	....	....	....	....	....	.020	.041	.049	.036
C	....	....	.074	.070	.060	.044	.032	.030	.043	.031
D	....	....	....	....	....	....	.033	.051	.065	.046

6. Ratio of Tons Sucrose to Tons Dry Weight:

The effects from increased nitrogen upon this ratio are quite small but nevertheless indicate a slight reduction in the ratio of sucrose to dry weight when the nitrogen was increased (compare A vs. C; A vs. B; C vs. D).

RATIO OF TONS SUCROSE TO TONS DRY WEIGHT

Treatment	Harvested in— July	Sept.	Nov.	Dec.	Jan.	Feb.	Mar.	June	Sept.	Dec.
X	.04	.10	.27	.28	.34	.36	.40	.35	.37	.37
A	.04	.12	.24	.29	.35	.39	.42	.37	.42	.40
B	...	...	...	...	...	...	.41	.34	.39	.39
C	...	...	.23	.25	.33	.36	.40	.37	.41	.38
D	...	...	...	...	...	...	.41	.33	.39	.39

7. Ratio of Commercial Sugar to Total Dry Weight:

In general the ratio of commercial sugar to total dry weight is also slightly lower from the higher amounts of nitrogen which were applied.

At the final harvest in December we note that approximately only 30 per cent of the total dry weight was commercial sugar, although some 39 per cent has been shown to be sucrose, and 44 per cent was total sugars.

RATIO TONS COMMERCIAL SUGAR TO TOTAL DRY WEIGHT

Treatment	Harvested in			
	March	June	Sept.	Dec.
X	.34	.30	.25	.30
A	.33	.32	.30	.31
B	.31	.28	.20	.31
C	.30	.29	.26	.29
D	.30	.26	.26	.27

8. Ratio of Per Cent Reducing Sugars to Per Cent Sucrose in Leaf Sheaths:

As a matter of interest, this ratio was calculated from the percentage of reducing sugars and of sucrose in the leaf-sheath samples taken from the crop at the last four harvests (Table 25 in Appendix). These ratios from the leaf-sheath samples are in agreement with the same ratios calculated from the total dry weight, i.e., the increased nitrogen applications have increased the ratios of per cent reducing sugars to per cent sucrose

RATIOS OF PER CENT REDUCING SUGARS TO PER CENT SUCROSE IN LEAF SHEATHS

Treatment	Harvested at			
	11½ mos.	14½ mos.	17½ mos.	20½ mos.
X	.26	.34	.66	.77
A	.54	.55	.70	.83
B	.42	.86	1.01	.96
C	.67	.74	.96	.98
D	.70	1.12	1.29	1.08

Discussion and Summary

The significant points which this study has brought out have already been discussed. Unfortunately we have again been unable to prove that the differences in yields secured at the final harvest from the field experiment in February at 23 months were significant effects of the nitrogen treatments.

WAIPIO EXPERIMENT 108 ATN—SECOND RATOON—HARVESTED AT 23 MONTHS
ANALYSIS OF VARIANCE

Source	Degrees of freedom	Mean squares		
		for TCA	Y%C	for TSA
Blocks	7	93.28	5.89	6.06
Treatments	3	380.33	1.86	.62
Error	21	152.47	1.47	.39
Coef. of Variation		9.6%	12.3%	5.0%

No significent effects of treatment

SUMMARY OF SECOND RATOON YIELDS (AVERAGE FROM 8 PLOTS)

Plot	Pounds N applied					Yields per acre (gross area)		
identity	June	July	Sept.	Feb.	Total	T.C.A.	Y%C	T.S.A.
A	40	60	0	0	100	119.3	10.3	12.1
B	40	60	0	60	160	127.8	9.9	12.5
C	40	60	60	0	160	131.5	9.8	12.8
D	40	60	60	60	220	135.4	9.1	12.3

No significant differences

Although it is somewhat hazardous to assume that Treatment C, and perhaps B, from their 160 pounds of N have produced more sugar than Treatment A (100 pounds N), and that there were no further gains from 220 pounds (Treatment D) over 160 pounds, we nevertheless have made this assumption. Hence, only insofar as it can be proved eventually that this assumption was correct can our interpretations also be considered valid.

We would point out the following as being the more specific effects which we feel have been found from this second ratoon crop of 32-8560:

1. The soil in this experimental area has continued to supply the crop with available nitrogen, and for a considerable period of time this amount was well over 100 pounds per acre.

2. Increased nitrogen applications have increased the number of millable stalks of cane, especially the number of suckers, but with this increase has also come an increase in stalk mortality as the age of the crop advanced.

3. Both total green and dry weights were increased as extra nitrogen was supplied. The extra nitrogen increased the amount of cane tops.

4. Nitrogen has increased the percentage of moisture and decreased the percentage of fiber found in this ratoon crop.

5. The concentration of reducing sugars was increased and there were probably some decreases in sucrose as a result of the increased nitrogen supplies.

6. Each increase in nitrogen applied was reflected by increased percentages of N in the total crop, in the active leaves, and in the cane juices.

7. Decreased percentages of P_2O_5 and of K_2O were found whenever the percentages of N were increased.

8. The Clements' "primary index" or per cent total sugars in leaf sheaths failed to indicate any reliable guidance for further nitrogen fertilization: a positive rather than negative relationship was found between increased nitrogen applications and the total sugars in leaf sheaths.

9. Cane quality was adversely affected by increased nitrogen.

10. Weather factors had different effects on yields at different crop-age periods.

If we accept the opinion that Treatments C and B produced more commercial sugar than Treatment A, and that Treatment D did not produce a further gain over Treatment C or B, then we can consider the following nitrogen levels found from Treatment A at 10½ months as being too low for the production of optimum sugar yields a year later:

(a) .29 per cent N in total dry weight, (b) 1.36 per cent N in leaf-punch samples, and (c) .013 per cent N in crusher juices. With the same assumption, an index of a supply of N at 10½ months which is apparently adequate to carry the crop through another year would be (a) .40 per cent N in the total dry weight, (b) 1.53 per cent N in the leaf-punch samples, and (c) .023 per cent N in the crusher juices. Apparently the critical level for nitrogen in the dry weight, or in the leaf blade, or in the crusher juices, is going to be within a very narrow range, and it will be necessary to reduce the sampling errors in our measurements, if we expect to identify it with a degree of accuracy needed to assure its use for guidance in nitrogen fertilization.

Acknowledgment

The cooperation and assistance supplied by the staffs of the research laboratories, of the chemistry and agricultural departments, and of the Waipio Substation is gratefully acknowledged. They have performed the work of sampling and the analyses which has made possible the presentation of the results.

APPENDIX

Containing Summaries of Data and Statistical Measurements Thereof From Waipio Expt. 108 ATN—Second Ratoon Crops

(Measurements from the 3 "X" Plots were not included in the Statistical Computations)

S.D.—Standard Deviation

C.V.—Coefficient of Variation

M.d.r.—Minimum difference required for significance between Treatments A, B, C, and D only

ns—Treatment effect not significant

TABLE I

TOTAL GREEN WEIGHT—TONS PER ACRE

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	7.1	23.6	34.8	40.0	42.2	32.5	51.2	57.0	96.1	89.9
A	11.0	42.1	58.9	64.9	73.2	77.7	89.8	115.4	124.2	114.6
B	....	....	....	....	....	....	84.1	101.6	142.4	144.5
C	....	....	72.4	67.5	81.5	79.0	100.5	122.8	160.7	120.7
D	....	....	....	....	....	....	97.0	140.1	151.7	148.8
S.D.	4.7	12.5	17.4	20.7	23.5	22.2	24.6	40.4	44.4	35.4
C.V.	42.9	29.8	26.4	31.2	30.4	28.3	26.5	33.7	30.7	26.8
M.d.r.	ns	ns	12.4	ns	ns	ns	ns	ns	ns	ns

TABLE 2

PER CENT TOPS IN TOTAL GREEN WEIGHT

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	100.00	51.27	28.80	31.07	27.42	27.60	20.05	17.69	16.00	14.93
A	100.00	43.17	32.32	26.82	23.54	20.23	16.49	14.29	12.49	11.16
B	.....	.....	.....	.....	.....	.....	18.14	17.86	13.65	10.92
C	.....	.....	30.61	27.03	22.51	20.50	18.65	15.02	10.87	13.04
D	.....	.....	.....	.....	.....	.....	16.73	16.62	11.87	10.45
S.D.	.....	4.95	4.43	3.83	3.59	3.10	3.22	3.53	1.50	2.45
C.V.	.....	11.5	14.1	14.2	15.6	15.2	18.4	22.1	12.3	21.5
M.d.r.	.....	ns	ns	ns	ns	ns	ns	ns	1.56	ns

TABLE 3

PER CENT MOISTURE IN TOTAL GREEN WEIGHT

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	78.58	78.46	77.47	75.72	75.72	73.43	72.47	72.24	74.34	75.40
A	80.12	79.97	77.90	76.89	76.46	75.07	73.93	72.31	73.33	73.79
B	.....	.....	.....	.....	.....	.....	73.62	75.54	75.40	74.84
C	.....	.....	79.58	79.22	77.97	76.17	74.26	73.77	74.83	74.44
D	.....	.....	.....	.....	.....	.....	74.73	76.05	77.33	75.47
S.D.	1.22	1.75	1.20	1.27	1.40	1.60	1.47	1.39	1.25	1.34
C.V.	1.5	2.2	1.5	1.6	1.8	2.1	2.0	1.9	1.7	1.8
M.d.r.	.....	.....	.89	.93	1.01	ns	ns	1.46	1.31	ns

TABLE 4

PER CENT FIBER IN TOTAL GREEN WEIGHT

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	16.12	16.29	14.24	15.39	15.11	15.80	14.97	16.73	15.81	15.16
A	16.19	14.62	14.76	14.18	14.35	14.20	13.76	15.62	15.70	14.85
B	.....	.....	.....	.....	.....	.....	14.35	14.48	15.06	14.65
C	.....	.....	13.54	13.05	13.53	13.52	13.84	15.03	14.79	14.64
D	.....	.....	.....	.....	.....	.....	13.71	14.08	14.17	14.28
S.D.	1.27	1.23	.78	.88	.92	1.12	1.02	1.09	.68	.90
C.V.	7.8	8.4	5.5	6.5	6.6	8.1	7.3	7.4	4.6	6.2
M.d.r.	....	.....	.58	.64	.66	ns	ns	ns	.71	ns

TABLE 5

TOTAL DRY WEIGHT—TONS PER ACRE

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	1.45	4.96	7.89	9.74	10.20	8.65	14.03	15.80	24.53	21.89
A	2.13	8.38	12.99	14.89	17.19	19.44	23.35	31.73	32.91	29.98
B	....	....	....	....	....	....	22.25	24.61	34.60	36.22
C	....	....	14.82	14.01	18.09	18.89	25.64	32.00	40.00	30.67
D	....	....	....	....	....	....	24.56	33.32	34.42	36.46
S.D.	.85	2.52	3.84	4.56	5.45	5.90	6.23	9.65	10.24	8.67
C.V.	39.9	30.0	27.6	31.7	31.0	30.7	26.0	31.7	28.8	26.0
M.d.r.	....	....	ns	ns	ns	ns	ns	ns	ns	ns

TABLE 6

PER CENT REDUCING SUGARS IN TOTAL DRY WEIGHT

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	4.14	5.82	4.01	2.09	1.99	1.17	1.06	1.77	2.63	1.92
A	4.92	9.01	5.46	4.27	3.90	2.85	2.19	2.04	2.48	2.24
B	....	....	....	....	....	....	1.92	3.90	4.73	3.54
C	....	....	7.42	7.06	6.26	4.48	3.16	3.05	4.26	3.09
D	....	....	....	....	....	....	3.31	4.97	6.45	4.54
S.D.	1.39	1.18	1.29	1.32	1.35	1.16	1.02	.84	.95	.75
C.V.	28.3	13.1	20.0	23.3	26.6	31.7	38.6	24.1	21.2	22.4
Md.r	....	....	.95	.97	.99	.85	1.06	.87	1.00	.79

TABLE 7

PER CENT SUCROSE IN TOTAL DRY WEIGHT

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	4.01	9.76	27.40	28.30	33.77	35.29	39.12	35.48	36.97	37.48
A	4.29	11.28	23.42	28.83	34.68	37.99	41.52	37.40	41.92	39.43
B	....	....	....	....	....	....	40.95	33.75	38.82	38.80
C	....	....	22.81	24.70	32.15	35.89	40.71	37.02	41.06	38.30
D	....	....	....	....	....	....	40.47	33.47	39.32	38.87
S.D.	.94	2.34	3.39	3.22	2.85	2.54	2.16	2.71	2.82	1.92
C.V.	21.9	20.7	14.7	12.0	8.5	6.9	5.3	7.7	7.0	4.9
Md.r.	....	....	ns	2.36	2.07	1.86	ns	2.81	ns	ns

TABLE 8

PER CENT TOTAL SUGARS IN TOTAL DRY WEIGHT

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	8.36	16.10	32.86	31.88	37.56	38.32	41.92	39.11	41.55	41.37
A	9.43	20.88	30.11	34.62	40.36	42.84	45.89	41.40	46.60	43.75
B	....	....	....	....	....	....	44.90	39.43	45.59	44.38
C	....	....	31.30	33.13	40.10	42.26	45.64	42.01	47.48	43.43
D	....	....	....	....	....	....	45.91	40.27	47.96	45.46
S.D.	1.76	2.14	3.11	3.17	2.38	2.51	2.60	2.52	2.52	1.98
C.V.	18.7	10.2	10.1	9.4	5.9	5.9	5.7	6.2	5.4	4.5
M.d.r.	....	....	ns	ns	ns	ns	ns	ns	ns	ns

TABLE 9

PER CENT NITROGEN IN TOTAL DRY WEIGHT

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	.868	.504	.322	.316	.292	.268	.201	.221	.212	.237
A	.993	.604	.408	.344	.320	.293	.240	.207	.192	.211
B	....	....	....	....	....	....	.293	.310	.236	.228
C	....	....	.542	.493	.436	.396	.325	.264	.229	.252
D	....	....	....	....	....	....	.369	.362	.280	.254
S.D.	.132	.065	.056	.047	.047	.040	.041	.035	.038	.035
C.V.	13.3	10.8	11.8	11.2	12.4	11.6	13.4	12.2	16.2	14.8
M.d.r.	....	....	.041	.035	.035	.029	.042	.037	.040	ns

TABLE 10

PER CENT P_2O_5 IN TOTAL DRY WEIGHT

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	.736	.471	.359	.341	.351	.320	.264	.300	.334	.341
A	.591	.330	.264	.272	.254	.254	.206	.204	.239	.256
B	....	....	....	....	....	....	.204	.200	.202	.218
C	....	....	.262	.278	.246	.230	.189	.179	.205	.224
D	....	....	....	....	....	....	.177	.175	.187	.200
S.D.	.075	.040	.025	.032	.038	.035	.030	.027	.026	.031
C.V.	12.7	12.1	9.5	11.6	15.2	14.5	15.5	14.3	12.5	13.8
M.d.r.	....	....	ns	ns	ns	ns	ns	ns	.027	.031

TABLE 11

PER CENT K_2O IN TOTAL DRY WEIGHT

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	2.57	2.47	2.059	1.593	1.950	1.748	1.463	1.474	1.375	1.591
A	2.44	1.87	1.626	1.251	1.405	1.304	1.244	1.040	1.009	1.045
B	....	....	....	....	....	....	1.243	1.156	.873	.833
C	....	....	1.486	1.208	1.297	1.161	1.065	.965	.832	.814
D	....	....	....	....	....	....	1.082	.915	.763	.680
S.D.	.21	.34	.173	.151	.225	.220	.175	.133	.109	.166
C.V.	8.6	18.2	11.1	12.2	16.7	17.9	14.7	13.1	12.5	19.7
M.d.r.	....	....	.124	ns	ns	ns	ns	.137	.114	.173

TABLE 12

PER CENT NITROGEN IN LEAF-PUNCH SAMPLES

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	1.47	1.25	1.18	1.18	1.15	1.05	1.03	1.06	1.19	1.40
A	1.63	1.53	1.41	1.39	1.38	1.36	1.32	1.23	1.24	1.41
B	....	....	....	....	....	....	1.43	1.44	1.36	1.47
C	....	....	1.60	1.59	1.54	1.53	1.45	1.38	1.35	1.47
D	....	....	....	....	....	....	1.53	1.51	1.42	1.54
S.D.	.05	.06	.05	.05	.05	.05	.08	.07	.06	.05
C.V.	3.1	3.9	3.3	3.4	3.4	3.5	5.6	5.0	4.4	3.4
M.d.r.	....	....	.04	.04	.04	.04	.09	.08	.07	.05

TABLE 13

PER CENT NITROGEN IN CRUSHER JUICES

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	....	.017	.010	.010	.008	.009	.010	.010	.009	.011
A	....	.021	.012	.012	.012	.013	.013	.010	.009	.012
B	....	....	....	....	....	....	.017	.017	.013	.015
C	....	....	.021	.020	.022	.023	.025	.018	.016	.016
D	....	....	....	....	....	....	.029	.021	.019	.019
S.D.	....	.004	.003	.003	.004	.004	.007	.005	.004	.003
C.V.	....	19.0	17.6	18.8	23.5	22.2	33.3	31.3	28.6	20.0
M.d.r.	....	....	.002	.002	.003	.003	.006	.006	.004	.004

TABLE 14

PER CENT TOTAL SUGARS IN LEAF SHEATHS

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	....	10.030	6.973	6.232	6.501	8.869	9.495	10.769	7.233	6.447
A	....	11.795	7.731	7.201	7.256	9.134	10.134	11.571	9.812	7.994
B	....	....	....	....	....	....	11.446	11.801	10.731	9.444
C	....	....	9.602	8.702	9.402	10.396	12.339	12.375	12.014	9.757
D	....	....	....	....	....	....	12.333	12.572	11.781	10.425
S.D.	....	1.609	.663	.539	1.109	1.288	1.652	.900	.943	.800
C.V.	....	13.6	7.6	6.8	13.3	13.2	14.3	7.5	8.5	8.5
M.d.r.	....	....	.484	.395	.811	.952	1.718	ns	.982	.832

TABLE 15

PER CENT MOISTURE IN LEAF SHEATHS

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	.....	80.60	80.63	80.15	79.86	77.91	77.39	76.76	77.42	81.43
A	.....	80.90	81.00	80.68	81.16	80.84	79.51	78.23	78.65	79.17
B	.....	.....	.....	.....	.....	.....	79.90	79.81	79.68	79.54
C	.....	.....	83.18	82.93	82.56	81.81	80.22	79.05	79.37	79.99
D	.....	.....	.....	.....	.....	.....	80.40	80.52	80.47	80.11
S.D.	.....	1.64	1.17	1.15	1.19	1.26	1.52	1.42	1.11	1.09
C.V.	.....	2.0	1.4	1.4	1.5	1.5	1.9	1.9	1.4	1.4
M.d.r.	.....	.....	.85	.85	.87	.93	ns	1.48	1.16	ns

TABLE 16

REDUCING SUGARS—TONS PER ACRE

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	.06	.30	.31	.21	.20	.10	.13	.28	.66	.44
A	.11	.75	.72	.64	.69	.54	.52	.69	.83	.69
B	...	...	...	...	...	...	.44	1.00	1.71	1.32
C	...	...	1.10	.99	1.08	.83	.83	.97	1.75	.96
D	...	...	...	...	...	...	.80	1.69	2.25	1.68
S.D.	.07	.24	.30	.28	.35	.25	.32	.50	.70	.46
C.V.	63.6	32.0	33.0	32.9	39.8	36.8	49.2	46.3	42.9	39.7
M.d.r.	...	...	.23	.21	.25	.19	.33	.52	.73	.48

TABLE 17

SUCROSE—TONS PER ACRE

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	.06	.49	2.16	2.73	3.43	3.13	5.61	5.60	9.06	8.17
A	.09	.98	3.09	4.33	5.99	7.50	9.72	11.85	13.81	11.88
B	...	...	...	...	...	...	9.18	8.32	13.34	14.03
C	...	...	3.38	3.50	5.93	6.79	10.38	11.89	16.41	11.71
D	...	...	...	...	...	...	9.98	11.09	13.30	14.15
S.D.	.05	.41	1.08	1.52	2.08	2.43	2.70	3.62	3.96	3.52
C.V	55.6	41.8	33.3	38.8	34.9	34.2	27.6	33.5	27.9	27.3
M.d.r.	...	...	ns	ns	ns	ns	ns	ns	ns	ns

TABLE 18

TOTAL SUGARS—TONS PER ACRE

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	.12	.82	2.59	3.13	3.80	3.39	6.02	6.18	10.20	9.03
A	.21	1.78	3.97	5.19	7.01	8.44	10.75	13.16	15.36	13.19
B	..	..	..	..	..	..	10.08	9.75	15.75	16.09
C	..	..	4.64	4.69	7.33	7.97	11.69	13.48	19.04	13.30
D	..	..	..	..	..	..	11.31	13.38	16.26	16.57
S.D.	.12	.62	1.33	1.78	2.42	2.67	3.08	4.17	4.71	4.17
C.V.	57.1	34.8	30.9	36.0	33.8	32.6	28.0	33.6	28.4	28.2
M.d.r.	..	..	ns	ns	ns	ns	ns	ns	ns	ns

TABLE 19

MILLABLE CANE—TONS PER ACRE

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	..	11.7	24.7	27.8	30.4	23.8	41.4	47.0	80.4	76.9
A	..	24.2	40.3	48.0	56.5	62.5	75.3	98.8	108.9	102.3
B	..	..	..	..	..	..	68.8	83.5	123.5	128.8
C	..	..	50.2	49.6	63.4	63.0	81.7	105.0	143.4	105.2
D	..	..	..	..	..	..	81.1	116.6	133.7	133.2
S.D.	..	'8.19	12.49	16.71	19.59	18.68	21.06	34.93	39.65	32.68
C.V.	..	33.8	27.6	34.2	32.7	29.8	27.5	34.6	31.1	27.8
M.d.r.	..	..	9.1	ns	ns	ns	ns	ns	ns	ns

TABLE 20

COMMERCIAL SUGAR—TONS PER ACRE

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	..	.02	1.3	2.0	2.6	2.4	4.7	4.8	6.2	6.5
A	..	.03	1.6	2.9	3.9	5.4	7.8	10.1	9.9	9.3
B	..	..	..	..	..	..	7.0	7.0	9.0	11.2
C	..	..	1.3	1.9	3.4	4.7	7.7	9.2	10.4	9.0
D	..	..	..	..	..	..	7.4	8.5	8.8	9.7
S.D.	..	.09	.78	1.03	1.35	2.01	2.31	2.89	2.65	3.16
C.V.	..	300.0	52.0	42.9	37.5	39.4	30.8	33.2	27.9	32.2
M.d.r.	..	..	ns	.8	ns	ns	ns	ns	ns	ns

TABLE 21

YIELD PER CENT CANE

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	..	.13	5.2	7.2	8.6	10.0	11.2	10.0	7.8	8.5
A	..	.15	4.0	6.2	7.0	8.5	10.3	10.4	9.3	9.2
B	..	..	..	..	..	..	10.0	8.5	7.4	8.6
C	..	..	2.5	3.8	5.3	7.4	9.5	8.8	7.5	8.6
D	..	..	..	..	..	..	9.1	7.4	6.6	7.4
S.D.	..	.38	1.33	1.17	1.42	1.19	1.27	.95	1.11	1.19
C.V.	..	253.3	40.3	23.4	23.3	14.9	13.1	10.8	14.4	14.2
M.d.r.	..	..	1.0	.8	1.0	.9	ns	1.0	1.1	1.2

TABLE 22

NITROGEN IN TOTAL DRY WEIGHT—POUNDS PER ACRE

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	25.0	50.3	51.0	61.2	59.7	46.4	55.6	70.1	106.9	103.7
A	41.4	100.5	105.3	103.3	109.3	111.1	112.4	133.9	127.7	125.8
B	..	..	..	..	..	..	129.3	154.3	165.0	172.6
C	..	..	161.2	136.9	153.9	149.2	169.3	170.3	184.7	155.5
D	..	..	..	..	..	..	180.1	241.9	191.9	184.9
S.D.	15.11	31.28	38.43	36.78	41.53	34.23	43.61	65.98	55.73	52.73
C.V.	36.5	31.1	28.9	30.6	31.6	26.3	29.5	37.7	20.8	33.0
M.d.r	..	..	28.1	26.9	30.4	25.0	45.3	68.6	ns	ns

TABLE 23

P_2O_5 IN TOTAL DRY WEIGHT—POUNDS PER ACRE

Plots	3½ mos. July '44	5½ mos. Sept.	7½ mos. Nov.	8½ mos. Dec.	9½ mos. Jan. '45	10½ mos. Feb.	11½ mos. Mar.	14½ mos. June	17½ mos. Sept.	20½ mos. Dec.
X	21.7	45.8	57.2	65.0	71.4	54.9	70.8	94.3	163.8	148.2
A	24.8	55.0	68.1	81.6	87.4	96.1	97.3	130.8	157.3	150.6
B	..	..	..	..	..	..	87.9	99.2	139.5	156.4
C	..	..	76.5	77.5	87.7	87.1	96.8	111.8	165.1	137.3
D	..	..	..	..	..	..	85.9	116.5	128.3	144.2
S.D.	8.48	15.92	18.52	28.35	29.60	24.23	20.11	38.52	41.59	37.02
C.V.	34.2	28.9	25.6	35.7	33.8	26.5	21.9	33.6	28.2	25.2
M.d.r.	..	..	ns	ns	ns	ns	ns	ns	ns	ns

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